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# Sediment Quality Values Refinement. Volume 2. Evaluation of PSDDA (Puget Sound Dredged Disposal Analysis) Quality Values (Appendices A and B)

PTI Environmental Services, Bellevue, WA

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**Puget Sound Estuary Program**

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# Sediment Quality Values Refinement: Volume II

# EVALUATION OF PSDDA SEDIMENT QUALITY VALUES

FINAL REPORT

September 1988

Prepared for
U.S. Environmental Protection Agency
Region 10 - Office of Puget Sound
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**7. Author(s)** R. Barrick, L. Brown, and S. Becker

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This report contains a detailed evaluation of the predictive reliability of dredged material disposal guidelines developed by the Puget Sound Dredged Disposal Analysis program. These guidelines were developed for use in evaluating the acceptability of dredged material for disposal in unconfined, open-water sites in Puget Sound and incorporate the following two kinds of sediment quality values: screening levels (sediment contamination below screening levels is assumed suitable for disposal without confirming biological tests); and maximum levels (the maximum levels indicate a level of chemical contamination above which a preponderance of toxicity information indicates the likelihood of unacceptable adverse biological effects). Evaluations conducted for this report indicate that current PSDDA screening and maximum level values are generally reliable in predicting adverse biological effects. Of 201 benthic infauna field samples and 287 amphipod bioassays field samples evaluated, approximately 93 percent are in accordance with the predictions of PSDDA values (i.e., they do not exhibit adverse effects at chemical concentrations below the screening levels and do exhibit adverse effects at concentrations above the maximum levels.)

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3625 132nd Avenue SE
Suite 301
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## VOLUME II

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# SEDIMENT QUALITY VALUES REFINEMENT: EVALUATION OF PSDDA SEDIMENT QUALITY VALUES

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by

R. Barrick, L. Brown, and S. Becker

Submitted to

Tetra Tech, Inc.
11820 Northup Way, Suite 100
Bellevue, WA 98005

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# EXECUTIVE SUMMARY

During 1986 and 1987, the Office of Puget Sound, U.S. Environmental Protection Agency Region 10, the U.S. Army Corps of Engineers Seattle District, and the Washington Departments of Ecology and Natural Resources undertook a joint effort to develop sediment quality values for Puget Sound. The goal of the project was to identify concentrations of chemicals in sediments that are expected (based on field evidence or theoretical predictions) to be associated with adverse biological effects. The specific objectives of the study were to compile synoptic biological and chemical data from Puget Sound, to evaluate techniques that could be used to develop chemical-specific sediment quality values, and to evaluate the reliability (i.e., ability to correctly identify sites with known biological effects) of the values generated using different techniques. The study was completed in September 1986 and copies of the final report (Beller et al. 1986) were distributed nationally and in the Puget Sound region.

The 1986 report contains an evaluation of several different approaches to establishing sediment quality values and ranges of chemical values that can be applied in sediment management, but does not identify the specific methods or values that the agencies will adopt for regulation or how these numerical values should be modified for application in specific regulatory programs.

Based on the conclusions of the 1986 report, the agencies requested a more detailed evaluation of the use of the Apparent Effects Threshold (AET) approach in establishing sediment quality values. An AET is defined as the sediment concentration of a contaminant above which statistically significant ($P \leq 0.05$) adverse effects for a particular biological indicator are always expected relative to appropriate reference conditions. AET are considered distinct from sediment quality values. AET are tools that can be used in sediment management. Sediment quality values, which may be based in part on AET, have yet to be adopted by Puget Sound agencies and, as a policy decision, may include safety factors or other modifications. This report does not address policy decisions for use of AET by agencies. It is recommended that the AET values not be applied outside Puget Sound without further evaluations.

The overall objective of the sediment quality values refinement project is to further test the reliability of AET and potential resulting sediment quality values based on AET in predicting adverse biological effects, and to provide more detailed analyses of the relationships between chemical concentrations and biological effects. The purpose of this report is to evaluate the effectiveness of dredged material disposal guidelines developed by the Puget Sound Dredged Disposal Analysis program. These guidelines, which were developed for use in evaluating the acceptability of dredged material for disposal in unconfined, open-water sites in Puget Sound, incorporate the following two kinds of sediment quality values (Phillips et al. 1988):

- Screening levels (SL)--sediment quality values based primarily on AET modified with a safety factor and used to evaluate when biological testing should be conducted on relatively uncontaminated sediment. Sediment contaminated below the SL is assumed to be suitable for disposal (i.e., exhibits minimal biological effects) without confirming biological tests.

- Maximum levels (ML)--sediment quality values based primarily on the highest AET (HAET) for a range of biological indicators and used to evaluate when biological testing may be unnecessary to determine that a contaminated sediment is unsuitable for disposal in certain environments. The ML is intended to indicate a level of chemical contamination above which there is a preponderance of evidence for unacceptable adverse biological effects.

The following four objectives were accomplished as part of the PSDDA evaluations:

1. Evaluate the sensitivity of PSDDA SL values in identifying all stations with significant biological effects
2. Evaluate the efficiency of PSDDA ML values in identifying only stations with significant biological effects
3. Evaluate the reliability of combinations of AET for multiple biological indicators in predicting adverse biological effects
4. Investigate ways to modify sediment quality values to achieve 100 percent reliability in predicting adverse biological effects.

Evaluations conducted for this report indicate that current PSDDA SL and ML values generally are reliable in predicting adverse biological effects. Of the 201 benthic infauna stations and 287 amphipod bioassay stations evaluated, approximately 93 percent (188 benthic stations and 264 amphipod stations) are in accordance with the prediction of the PSDDA ML and SL values (i.e., they do not exhibit adverse effects at chemical concentrations less than SL values and do exhibit adverse effects at chemical concentrations above ML values). One or the other of these biological indicators is still in accordance with predictions of PSDDA ML and SL values at 17 of the 22 remaining stations (77 percent) for which data for both benthic infauna and amphipod bioassays are available.

PSDDA SL values, used as guidelines for identifying the need for biological testing of dredged material, predict from 92 to 100 percent of the stations exhibiting adverse biological effects in the available 11-survey database for Puget Sound. Physical characteristics (e.g., grain size, habitat exposure), high detection limits, and/or unanalyzed chemicals are likely factors accounting for the nine amphipod and five benthic infauna stations that were incorrectly predicted as not having adverse effects by PSDDA SL values. Of these factors, grain size characteristics are considered most important. Sediments from five of the nine amphipod bioassay stations that were mispredicted were highly fine-grained (i.e., >75-90 percent), a naturally unfavorable habitat for the test organisms. Sediments from four of the five benthic infauna stations that were mispredicted were highly coarse-grained (i.e., 77-95 percent) and in some cases were collected in areas of relatively high-wave intensity compared to reference conditions. Both conditions are expected to result in reduced abundances of organisms that may not have been adequately controlled for by comparisons to reference area samples. Only one adverse biological impact was exhibited at the four stations mispredicted by SL values and at which two biological indicators were tested. Overall, there is no evidence suggesting that PSDDA SL values should be modified downward to further enhance their sensitivity. The focus of the SL evaluation was on sensitivity in identifying all impacts; however, the current SL values are 31 to 59 percent efficient in identifying only impacted stations (i.e., 41 to 69 percent of all stations predicted as potential problems by PSDDA SL values did not exhibit adverse biological effects). Sediment quality values modified to enhance sensitivity were comparable or somewhat lower in efficiency.

The apparent sensitivity of each biological indicator to different chemicals based on AET was also evaluated. The lowest AET (LAET) for the range of biological indicators is established by the Microtox bioassay for two metals (mercury and nickel), 20 of 53 organic chemicals, and one of five conventional variables (i.e., oil and grease). The benthic infauna indicator establishes the LAET for the other seven metals and for three organic compounds. The amphipod bioassay establishes two LAET and the oyster larvae bioassay establishes one LAET for organic chemicals. Seventeen LAET for organic chemicals and LAET for four conventional variables (sulfides, total organic carbon, total volatile solids, and total nitrogen) are established at the same concentration by more than one biological indicator (including amphipod mortality, oyster larvae abnormality, Microtox bioluminescence, or depressions in benthic infaunal abundance).

The 1986 HAET for the range of biological indicators is established by the amphipod bioassay for four metals (antimony, copper, mercury, and nickel), 17 of 53 organic compounds including PCBs, and three of five conventional variables. The benthic infauna indicator establishes the HAET for one metal (silver), 16 of 53 organic compounds including all individual and total HPAH, and one conventional variable (oil and grease). Nineteen HAET are established at the same concentration by more than one biological indicator (including oyster larvae and Microtox bioassays, although these indicators do not uniquely establish any HAET).

PSDDA ML values are used as guidelines for identifying contaminated sediments that are unsuitable for disposal at unconfined, open-water sites based on chemical data alone. Depending on the biological indicator, from 77 to 100 percent of the stations predicted by ML values to have adverse biological effects actually exhibited the effects predicted in the available 11-survey database for Puget Sound. The focus of the ML evaluation was on efficiency in identifying only impacted stations. This enhanced efficiency in detecting only problem sediments relative to PSDDA SL values is paralleled by a decrease in sensitivity. The current ML values are 24 to 43 percent sensitive in identifying all impacted stations in the database. Stations that did not exhibit all adverse effects that were predicted by ML values included 2 Eagle Harbor, 4 Everett Harbor, and 14 Elliott Bay stations. However, within this group of 20 stations, adverse impacts were observed for at least one biological indicator at 13 of the 18 stations at which both amphipod bioassays and benthic infauna analyses were conducted.

Chemical concentrations at 40 percent (8 of 20 stations) of these stations were within a factor of 2 of the PSDDA ML values, suggesting that enhancements in efficiency of ML values are possible with only minor revisions. Concentrations of single chemicals (i.e., anthracene or lead) exceeded ML values by more than a factor of 10 at one Eagle Harbor station and one Elliott Bay station at which the amphipod bioassay was not significant (although significant benthic impacts were observed). The concentration of mercury exceeded ML values by more than a factor of 10 at one Elliott Bay station at which the benthic infauna indicator was not significant (although significant amphipod mortality was observed).

Chemical concentrations generally exceeded ML values by less than a factor of two at the one Everett Harbor and three Elliott Bay stations at which neither biological indicator exhibited a significant response. However, the concentration of benzyl alcohol exceeded the ML value by more than a factor of 10 at one of the stations. These latter four stations represent less than 2 percent of the Puget Sound database.

1988 HAET are 100 percent efficient in predicting adverse effects for the 201 benthic infauna stations, 287 amphipod bioassay stations, 56 Microtox bioassay stations, and 50 oyster larvae bioassay stations included in the AET database. After including in the reliability analysis the nonimpacted stations that were identified as chemical anomalies (Barrick et al. 1988; Volume I), the efficiency of 1988 HAET is:

- 91 percent for benthic infauna stations (four nonimpacted benthic stations were excluded from 1988 AET calculations as chemical anomalies)
- 85 percent for amphipod bioassays (eight nonimpacted amphipod stations were excluded from 1988 AET calculations as chemical anomalies)
- 100 percent efficient for oyster larvae and Microtox bioassays (no stations were excluded).

Decision rules concerning the treatment of anomalous biological or chemical results (particularly single nonimpacted stations at which single chemical concentrations greatly exceed sediment quality values) are discussed in Volume I of this sediment quality values refinement report (Barrick et al. 1988; see Section 2.4 and Appendix C of Volume I). Revision of ML values to incorporate these anomalous stations is recommended on a case-by-case basis because such stations may reflect strictly localized, nonrepresentative conditions.

The 1988 HAET are as sensitive as PSDDA ML values in predicting depressions in benthic infaunal abundances or amphipod mortality. The 1988 HAET were 7 to 12 percent more sensitive than PSDDA ML values in predicting adverse responses for Microtox and oyster larvae bioassays. Such results are attributed to the contribution to sensitivity by additional chemicals not included as PSDDA chemicals of concern. When only PSDDA chemicals of concern for which there are ML values are considered, the 1988 HAET are still 100 percent efficient, but the sensitivity of 1988 HAET decreases to 32 percent for benthic infauna impacts (compared with 42 percent for ML values), and to 37 percent for amphipod bioassay impacts (compared with 43 percent for ML values). The sensitivity and efficiency of 1988 HAET and ML values are identical in predicting adverse impacts for Microtox and oyster larvae bioassays.

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The primary authors of this report are Mr. Robert Barrick, Ms. Lorraine Brown, and Dr. Scott Becker. Additional editorial review was provided by Ms. Carol Newlin. Mr. Dreas Nielsen and Dr. Chip Hogue developed SEDQUAL, the menu-driven database system used for conducting the extensive comparisons of sediment quality values provided in this report. Sponsoring agencies provided substantial support in defining the overall management context within which development of sediment quality values must occur.

# 1. INTRODUCTION

This report consists of an evaluation of the predictive capability of sediment quality values used as management tools in the Puget Sound Dredged Disposal Analysis (PSDDA) program. The work was conducted as part of the Sediment Quality Values Refinement project, which is sponsored by the Puget Sound Estuary Program (PSEP) through the Office of Puget Sound. Initiation of the study was approved by the Puget Sound Implementation Committee and Technical Advisory Committee. The results of this study are intended for use by PSEP and the PSDDA program, the Washington Department of Ecology (Ecology), and the Puget Sound Water Quality Authority in defining guidelines for managing contaminated sediments in Puget Sound. This report does not address policy decisions for use of sediment quality values by agencies. It is also recommended that these values not be applied outside Puget Sound without further evaluations.

Definitions of and methods used to evaluate PSDDA sediment quality values are summarized in Section 2. Results of the evaluations, which include validation tests using Puget Sound data, are presented in Section 3 and summarized in Section 4. References and a glossary of terms are provided in Sections 5 and 6, respectively. Written comments received by the sponsoring agencies from reviewers of the draft report have been incorporated in this final report whenever possible.

## 1.1 BACKGROUND

During 1986 and 1987, the Office of Puget Sound, U.S. Environmental Protection Agency (EPA) Region 10, the U.S. Army Corps of Engineers Seattle District, and the Washington Departments of Ecology and Natural Resources undertook a joint effort to develop sediment quality values for Puget Sound. This effort was funded by PSEP and PSDDA. The goal of the project was to identify concentrations of chemicals in sediments that are expected (based on field evidence or theoretical predictions) to be associated with adverse biological effects. The specific objectives of the study were:

- To compile synoptic biological and chemical data from Puget Sound (all data sets were evaluated for their appropriate use before proceeding)
- To establish correlations between levels of chemicals in the environment and observed biological effects
- To evaluate techniques that could be used to develop chemical-specific sediment quality values
- To evaluate the reliability (i.e., ability to correctly identify sites with known biological effects) of the values generated using different techniques.

The study was completed in September 1986 and copies of the final report (Beller et al. 1986) were distributed nationally and in the Puget Sound region.

The 1986 report contains an evaluation of several approaches to establishing sediment quality values and ranges of chemical values that can be applied in sediment management, but does not identify the specific methods or values that the agencies will adopt for regulation or how these numerical values should be modified for application in specific regulatory programs.

Based on the conclusions of the PSEP/PSDDA study, the agencies requested a more detailed evaluation of the use of the Apparent Effects Threshold (AET) method in establishing sediment quality values. AET is the sediment concentration of a chemical above which a particular adverse biological effect always is expected. AET are considered distinct from sediment quality values. AET are tools that can be used in sediment management. Sediment quality values, which may be based in part on AET, have yet to be adopted by PSEP or PSDDA and may include safety factors or other modifications. This report does not address policy decisions for use of AET by agencies. It is recommended that the AET values not be applied outside Puget Sound without further evaluations.

## 1.2 OBJECTIVES

The purpose of this report is to evaluate the effectiveness of dredged material disposal guidelines developed by PSDDA. These guidelines, which were developed for use in evaluating the acceptability of dredged material for disposal in unconfined, open-water sites in Puget Sound, incorporate the following two kinds of sediment quality values (Phillips et al. 1988):

- Screening levels (SL)--sediment quality values based primarily on AET modified with a safety factor and used to evaluate when biological testing should be conducted on relatively uncontaminated sediment. Sediment contaminated below the SL is assumed to be suitable for disposal (i.e., exhibits minimal biological effects) without confirming biological tests.

- Maximum levels (ML)--sediment quality values based primarily on the highest AET (HAET) for a range of biological indicators and used to evaluate when biological testing may be unnecessary to determine that a contaminated sediment is unsuitable for disposal in certain environments. The ML is intended to indicate a level of chemical contamination above which there is a preponderance of evidence for unacceptable adverse biological effects.

The evaluation presented in this report is only one of several tasks conducted under the sediment quality values refinement project (Figure 1). The overall objective of the project is to further test the reliability of AET and resulting sediment quality values based on AET in predicting adverse biological effects, and to provide more detailed analyses of the relationships between chemical concentrations and biological effects. The following four objectives were accomplished as part of the PSDDA evaluations:

1. Evaluate the sensitivity of PSDDA SL values in identifying all stations with significant biological effects

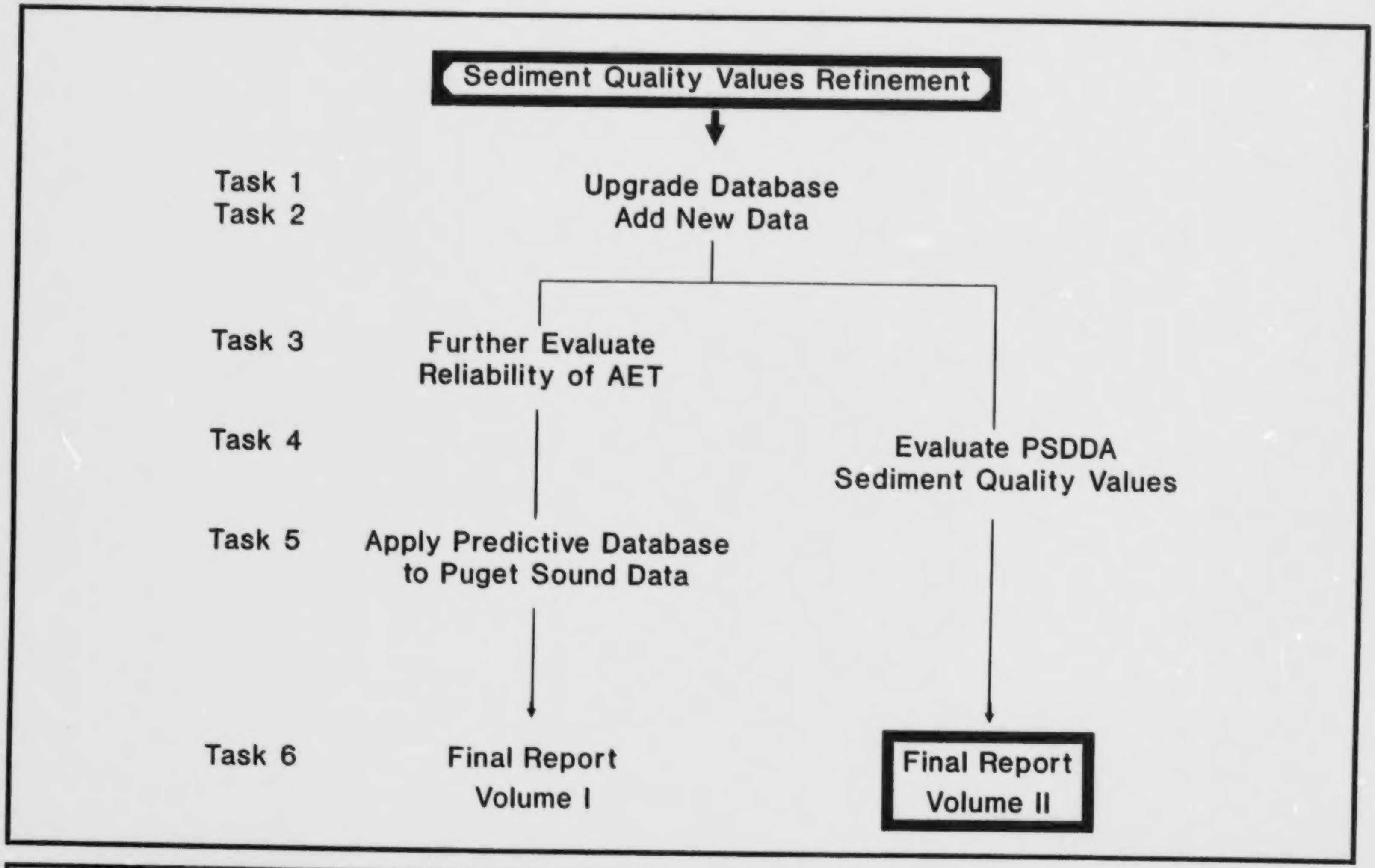

Sediment Quality Values Refinement
Task 1
Task 2
Upgrade Database
Add New Data
Task 3
Further Evaluate
Reliability of AET
Task 4
Evaluate PSDDA
Sediment Quality Values
Task 5
Apply Predictive Database
to Puget Sound Data
Task 6
Final Report
Volume I
Final Report
Volume II

Figure 1. Relationship of sediment quality values refinement tasks

2. Evaluate the efficiency of PSDDA ML values in identifying only stations with significant biological effects

3. Evaluate the reliability of combinations of AET for multiple biological indicators in predicting adverse biological effects

4. Investigate ways to modify sediment quality values to achieve 100 percent reliability in predicting adverse biological effects.

## 2. METHODS

Most analyses for this report were conducted using a menu-driven program (SEDQUAL) developed for the Puget Sound sediment quality values database. A detailed description of the database and menu-driven features is given in the SEDQUAL users manual (Nielsen 1988). In this section, a summary is provided of the AET approach, measures of reliability (i.e., sensitivity and efficiency of the chemical predictions of adverse biological effects), the definition of PSDDA SL and ML values, and the data sets used to establish and test the SL and ML values. Biological analyses and statistical procedures used to determine adverse biological effects have been summarized by Beller et al. (1986). Options to modify these procedures to account for statistical anomalies are discussed in Barrick et al. (1988; Volume I).

To accomplish the objectives listed in Section 1, various PSEP/PSDDA sediment quality values (e.g., PSDDA screening and maximum levels, AET for individual biological indicators, and highest and lowest AET (HAET and LAET) for the range of biological indicators) were compiled in SEDQUAL and used to compare against chemical concentration data for Puget Sound sediments. For each set of sediment quality values, calculations were performed to determine their reliability in correctly identifying impacted and nonimpacted stations in the Puget Sound database. Lists were compiled for evaluation of those stations that were incorrectly predicted by these sediment quality values (i.e., either exhibiting adverse biological effects when none was predicted, or not exhibiting adverse biological effects when one was predicted). Iterative procedures were developed and performed to modify sediment quality values to achieve 100 percent reliability in predicting adverse biological effects.

The reliability of PSDDA sediment quality values for antimony and nickel (two PSDDA metals of concern) is considered separately from the reliability of values for other chemicals in this report. Modifications of analytical procedures were instituted in PSEP protocols to better define the total concentration of these and other metals in sediments. These changes in analytical procedures were implemented in the Elliott Bay and Everett Harbor surveys conducted by PSEP (including reference area data collected in Port Susan). Additional tests conducted on sediment samples from Elliott Bay and Port Susan, and on archived sediment samples from Carr Inlet (a reference area in Southern Puget Sound) indicate that antimony concentrations are substantially higher with this revised technique than determined with the previous technique. As a result, 1986 AET values for antimony that are based on historical data by other metals analysis techniques are inefficient predictors of problem sediments in the new surveys. Definitive test results for X-ray fluorescence analyses also indicated that antimony measurements by other techniques (i.e., strong or total acid digestion) are less reliable than those for other metals. All but five test samples for antimony have been analyzed by these other techniques; hence, antimony AET values should be considered estimates only.

Nickel concentrations were comparable using the two metals digestion techniques. However, the range of nickel concentrations in the Puget Sound database prior to the addition of Elliott Bay and Everett Harbor data was narrow relative to Puget Sound reference concentrations. Thus, the 1986 AET for nickel was inefficient in reliably predicting adverse effects in the new surveys, which had a wider range of nickel concentrations. It is recommended that PSDDA sediment quality values for nickel and antimony be revised to reflect 1988 AET for amphipod bioassay and benthic infaunal analyses that include Elliott Bay and Everett Harbor surveys. Revised AET for these metals are evaluated in Barrick et al. (1988; Volume I).

## 2.1 MEASURES OF RELIABILITY: SENSITIVITY AND EFFICIENCY

Environmental factors such as matrix effects or chemical interactions can affect the ability to correctly predict adverse biological effects in environmental samples based on any chemical-specific criteria. The only way to definitively confirm the chemical-specific predictions (i.e., whether particular biological effects are always observed above a given sediment quality value) is to conduct controlled laboratory spiking studies. A second approach is to test field samples with known concentrations of the contaminant of concern but this approach does not directly quantify possible interactions among chemicals. However, the binary (impacted/nonimpacted) predictions of sediment quality values, which are most pertinent to sediment management, are testable using data sets that have matched chemical and biological data. Tests using such data are applicable to and recommended for assessing environmental predictions of any approach to developing sediment criteria as part of management performance objectives. The basic requirements of such tests of reliability are described in this section.

To meet the needs of most sediment quality management programs, an ideal sediment criteria approach would perform well on both of the following measures of reliability, which are evaluated with actual field data:

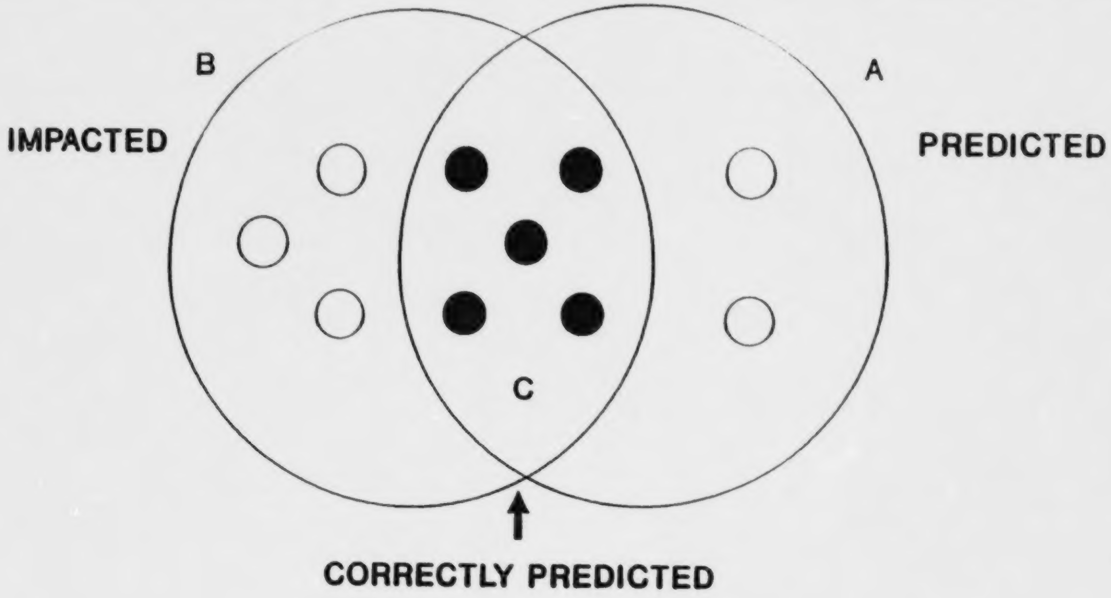
- **Sensitivity** in detecting environmental problems (i.e., are all biologically impacted sediments identified by the predictions of the chemical sediment criteria?)

- **Efficiency** in screening environmental problems (i.e., are only biologically impacted sediments identified by the predictions of the chemical sediment criteria?).

As a measure of reliability, sensitivity is defined as the proportion of all stations exhibiting a particular adverse biological effect that are correctly predicted using sediment quality values for that biological indicator. Efficiency is defined as the proportion of all stations predicted to have a particular adverse biological effect that actually are impacted. The concepts of sensitivity and efficiency are illustrated in Figure 2.

Sensitivity and efficiency are independent measures of reliability. For example, a sediment criteria approach that sets values for a wide range of chemicals near their analytical detection limits will probably be sensitive but inefficient. That is, it will predict a large percentage of sediments with biological effects but will also predict many biologically unimpacted sediments with only slightly elevated chemical concentrations. Such an approach may be environmentally protective but also may result in overregulation that would not be cost effective.

Conversely, a sediment criteria approach that sets values at the upper end of the range of environmental concentrations may be efficient but insensitive. That is, a high percentage of the stations with predicted impacts may indeed be biologically impacted,


B
A
IMPACTED
PREDICTED
C
CORRECTLY PREDICTED

SENSITIVITY = C/B x 100 = 5/8 x 100 = 63%

EFFICIENCY = C/A x 100 = 5/7 x 100 = 71%

FOR A GIVEN BIOLOGICAL INDICATOR:

A ALL STATIONS PREDICTED TO BE IMPACTED

B ALL STATIONS KNOWN TO BE IMPACTED

C ALL STATIONS CORRECTLY PREDICTED TO BE IMPACTED

Figure 2. Measures of reliability (sensitivity and efficiency).

but the approach may fail to predict other biologically impacted stations with moderate to high chemical concentrations. Such an approach may be cost-effective and defensible in pursuing high priority remedial actions (i.e., would not overregulate) but would not be environmentally protective.

The overall reliability of any sediment criteria approach addresses both components of sensitivity and efficiency. This measure is defined as the proportion of all stations for which correct predictions were made for either the presence or absence of adverse biological effects:

- **Overall reliability =** $$\frac{\left[\begin{array}{c}\text{All stations correctly predicted as impacted}\\ +\\ \text{All stations correctly predicted as nonimpacted}\end{array}\right]}{[\text{Total number of stations evaluated}]}$$

High reliability results from correct prediction of a large percentage of the impacted stations (i.e., high sensitivity; few false negatives) and correct prediction of a large percentage of the nonimpacted stations (i.e., high efficiency; few false positives). These measures of reliability are used as the primary means of evaluating PSDDA sediment quality values in this report.

## 2.2 SUMMARY OF AET APPROACH

PSDDA sediment quality values are based primarily on values developed from the AET approach. Regulatory sediment criteria based on definitive laboratory cause-effect studies and field verification studies are still under development. In the interim, field effects-based approaches using the AET concept provide decision tools that have the following characteristics:

- Developed empirically from field data
- Expressed as chemical-specific values
- Supported by a variety of biological indicators, including lethal and sublethal effects on different life stages of organisms *in situ* or under laboratory conditions
- Driven by statistically significant ($P \leq 0.05$) adverse effects
- Supported by non-contradictory evidence of adverse effects within a given data set used to calculate AET.

AET can be developed for any measured chemical (organic or inorganic) that spans a wide concentration range in the data set used to generate AET. The AET concept can be applied to matched field data for sediment chemistry and any observable biological effects (e.g., bioassay responses, infaunal abundances at various taxonomic levels, bioaccumulation). By using these different biological indicators, application of the resulting sediment quality values enables a wide range of biological effects to be addressed in the management of contaminated sediments.

The focus of the AET approach is to identify concentrations of contaminants that are associated exclusively with sediments exhibiting statistically significant biological effects relative to reference sediments. The calculation of AET for each chemical and biological indicator is straightforward:

1. **Collect "matched" chemical and biological effects data**--Conduct chemical and biological effects testing on subsamples of the same field sample (to avoid unaccountable losses of benthic organisms, benthic infaunal and chemical analyses are conducted on separate samples collected concurrently for the same station)

2. **Identify "impacted" and "nonimpacted" stations**--Statistically test the significance of adverse biological effects relative to suitable reference conditions (i.e., responses resulting from exposure to sediments containing very low or undetectable concentrations of any toxic chemicals) for each sediment sample and biological indicator

3. **Identify AET using only "nonimpacted" stations**--For each chemical, the AET can be identified for a given biological indicator as the highest detected concentration among sediment samples that do not exhibit statistically significant effects (if the chemical is undetected in all these samples, no AET can be established for that chemical and biological indicator)

4. **Check for preliminary AET**--Verify that statistically significant biological effects are observed at a chemical concentration higher than the AET; otherwise the AET is only a preliminary minimum estimate (or may not exist).

5. Repeat Steps 1-4 for each biological indicator.

Additional discussion of the AET concept and a pictorial representation of the AET approach for two example chemicals are provided in Appendix A. Puget Sound AET values based on biological effects data for eight surveys were previously generated and evaluated by PSEP and PSDDA in 1986 (Beller et al. 1986). These 1986 AET are summarized in Table 1 (dry weight normalization). Evaluations of AET that were recalculated in 1988 to include new data (e.g., surveys in Eagle Harbor, Elliott Bay, and Everett Harbor) are discussed in Barrick et al. (1988; Volume I). The HAET and LAET for the 1986 and 1988 AET are summarized in Table 2.

For comparison to HAET and LAET values in Table 2, a summary of concentration ranges of selected chemicals and key sediment characteristics [i.e., total organic carbon (TOC), fine-grained sediment content, sulfides] is provided in Table 3 for biological effects stations contained in the Puget Sound sediment quality values database. Data for two groups of biological samples are given in Table 3: sediments sampled from reference areas (nonurban embayments) and from nonreference areas of Puget Sound (frequently from industrialized, urban embayments). Reference areas in Puget Sound are generally removed from the direct influence of contaminant sources in nonurbanized areas of the sound; almost all of these stations are nonimpacted. Most data for nonreference areas are from industrialized urban embayments and include both nonimpacted and impacted stations.

## TABLE 1. 1986 PUGET SOUND AET FOR SELECTED CHEMICALS (dry weight)[a]

| Chemical | Amphipod AET[b] | Oyster AET[c] | Benthic AET[d] | Microtox AET[e] |
|---|---|---|---|---|
| **Metals** (mg/kg dry weight; ppm) | | | | |
| Antimony | 5.3 | 26 | 3.2 | 26 |
| Arsenic | 93 | 700 | 85 | 700 |
| Cadmium | 6.7 | 9.6 | 5.8 | 9.6 |
| Copper | 810[f] | 390 | 310 | 390 |
| Lead | 660 | 660 | 300 | 530 |
| Mercury | 2.1[f] | 0.59 | 0.88 | 0.41 |
| Nickel | >120[f] | 39 | 49 | 28 |
| Silver | >3.7[f] | >0.56 | 5.2 | >0.56 |
| Zinc | 870[f] | 1,600 | 260 | 1,600 |
| **Organic Compounds** (ug/kg dry weight; ppb) | | | | |
| Low molecular weight PAH | 5,200 | 5,200 | 6,100[f] | 5,200 |
| Naphthalene | 2,100 | 2,100 | 2,100 | 2,100 |
| Acenaphthylene | 560 | >560 | 640[f] | >560 |
| Acenaphthene | 630[f] | 500 | 500 | 500 |
| Fluorene | 540 | 540 | 640[f] | 540 |
| Phenanthrene | 5,400[f] | 1,500 | 3,200[f] | 1,500 |
| Anthracene | 1,900[f] | 960 | 1,300[f] | 960 |
| 2-Methylnaphthalene | 670 | 670 | 670 | 670 |
| High molecular weight PAH | 18,000[f] | 17,000 | >51,000[f] | 12,000 |
| Fluoranthene | 3,900[f] | 2,500 | 6,300[f] | 1,700 |
| Pyrene | 4,300[f] | 3,300 | >7,300[f] | 2,600 |
| Benz(a)anthracene | 1,600[f] | 1,600 | 4,500[f] | 1,300 |
| Chrysene | 2,800[f] | 2,800 | 6,700[f] | 1,400 |
| Benzofluoranthenes | 3,700 | 3,600 | 8,000[f] | 3,200 |
| Benzo(a)pyrene | 2,400 | 1,600 | 6,800[f] | 1,600 |
| Indeno(1,2,3-c,d)pyrene | 690[f] | 690 | >5,200[f] | 600 |
| Dibenzo(a,h)anthracene | 260[f] | 230 | 1,200[f] | 230 |
| Benzo(g,h,i)perylene | 740[f] | 720 | 5,400[f] | 670 |
| Chlorinated organic compounds | | | | |
| 1,3-Dichlorobenzene | >170 | >170 | >170 | >170 |
| 1,4-Dichlorobenzene | 260 | 120 | 120 | 110 |
| 1,2-Dichlorobenzene | >350 | 50 | 50 | 35 |
| 1,2,4-Trichlorobenzene | 51 | 64 | 64 | 31 |
| Hexachlorobenzene (HCB) | 130 | 230 | 230 | 70 |
| Total PCBs | 2,500[f] | 1,100 | 1,100 | 130 |
| Phthalates | | | | |
| Dimethyl phthalate | 160 | 160 | 160 | 71 |
| Diethyl phthalate | >73 | >73 | 97 | >48 |
| Di-n-butyl phthalate | >5,100 | 1,400 | >5,100 | 1,400 |

**TABLE 1. (Continued)**

| Chemical | Amphipod AET[b] | Oyster AET[c] | Benthic AET[d] | Microtox AET[e] |
|---|---|---|---|---|
| Phthalates (continued) | | | | |
| Butyl benzyl phthalate | >470 | >470 | 470 | 63 |
| Bis(2-ethylhexyl)phthalate | >3,100 | 1,900 | 1,900 | 1,900 |
| Di-n-octyl phthalate | >590 | >420 | >69,000 | -- |
| Phenols | | | | |
| Phenol | 670[f] | 420 | 1,200 | 1,200 |
| 2-Methylphenol | 63 | 63 | >72 | >72 |
| 4-Methylphenol | 1,200 | 670 | 670 | 670 |
| 2,4-Dimethyl phenol | >50 | 29 | 29 | 29 |
| Pentachlorophenol | >140 | >140 | >140 | >140 |
| Miscellaneous Extractables | | | | |
| Benzyl alcohol | 73 | 73 | 73 | 57 |
| Benzoic acid | >690 | 650 | 650 | 650 |
| Dibenzofuran | 540 | 540 | 540 | 540 |
| Hexachlorobutadiene | 290 | 270 | 270 | 120 |
| N-Nitrosodiphenylamine | 220 | 130 | 74 | 40 |
| Volatile Organics | | | | |
| Tetrachloroethene | >210 | 140 | 140 | 140 |
| Ethylbenzene | >50 | 37 | 37 | 33 |
| Total xylenes | >160 | 120 | 120 | 100 |
| Pesticides | | | | |
| p,p'-DDE | 15 | -- | 9 | -- |
| p,p'-DDD | 43 | -- | 2 | -- |
| p,p'-DDT | 3.9 | >6 | 11 | -- |

[a] ">" indicates that a defined AET could not be established because there were no "effects" stations with chemical concentrations above the highest concentration among "no effects" stations.

[b] Based on 150 stations.

[c] Based on 56 stations (all from Commencement Bay Remedial Investigation and Blair Waterway dredging study).

[d] Based on 94 stations.

[e] Based on 50 stations (all from Commencement Bay Remedial Investigation).

[f] The value shown exceeds AET established from Commencement Bay Remedial Investigation data (Barrick et al. 1985) because of addition of Puget Sound data presented in Beller et al. (1986).

## TABLE 2. 1986 AND 1988 LOWEST AET (LAET) AND HIGHEST AET (HAET) FOR SELECTED CHEMICALS IN PUGET SOUND (dry weight)[a]

| Chemical | 1986[b] | | 1988[c] | |
|---|---|---|---|---|
| | LAET | HAET | LAET | HAET |
| **Metals** (mg/kg dry weight; ppm) | | | | |
| Antimony | 3.2 | 26 | 150 | 250 |
| Arsenic | 85 | 700 | 57[d] | 700 |
| Cadmium | 5.8 | 9.6 | 5.1[d] | 9.6 |
| Copper | 310 | 810 | 390 | 1,300 |
| Lead | 300 | 660 | 450 | 660 |
| Mercury | 0.41 | 2.1 | 0.41 | 2.1 |
| Nickel | 28 | 120[e] | f | 140[e] |
| Silver | 5.2 | 5.2 | 5.2 | 6.1 |
| Zinc | 260 | 1,600 | 410 | 1,600 |
| **Organic Compounds** (ug/kg dry weight; ppb) | | | | |
| Low molecular weight PAH | 5,200 | 6,100 | 5,200 | 24,000 |
| Naphthalene | 2,100 | 2,100 | 2,100 | 2,700 |
| Acenaphthylene | 560 | 640 | 1,300 | 1,300 |
| Acenaphthene | 500 | 630 | 500 | 2,000 |
| Fluorene | 540 | 640 | 540 | 3,600 |
| Phenanthrene | 1,500 | 5,400 | 1,500 | 6,900 |
| Anthracene | 960 | 1,900 | 960 | 13,000 |
| 2-Methylnaphthalene | 670 | 670 | 670 | 1,900 |
| High molecular weight PAH | 12,000 | 51,000[e] | 12,000 | 69,000 |
| Fluoranthene | 1,700 | 6,300 | 1,700 | 30,000 |
| Pyrene | 2,600 | 7,300[e] | 2,600 | 16,000 |
| Benz(a)anthracene | 1,300 | 4,500 | 1,300 | 5,100 |
| Chrysene | 1,400 | 6,700 | 1,400 | 9,200 |
| Benzofluoranthenes | 3,200 | 8,000 | 3,200 | 9,900 |
| Benzo(a)pyrene | 1,600 | 6,800 | 1,600 | 3,600[d] |
| Indeno(1,2,3-c,d)pyrene | 600 | 5,200[e] | 600 | 2,600[d] |
| Dibenzo(a,h)anthracene | 230 | 1,200 | 230 | 970[d] |
| Benzo(g,h,i)perylene | 670 | 5,400 | 670 | 2,600[d] |
| Chlorinated organic compounds | | | | |
| 1,3-Dichlorobenzene | f | f | f | f |
| 1,4-Dichlorobenzene | 110 | 260 | 110 | 120[d] |
| 1,2-Dichlorobenzene | 35 | 350e | 35 | 110[d,e] |
| 1,2,4-Trichlorobenzene | 31 | 64 | 31 | 64 |
| Hexachlorobenzene (HCB) | 70 | 230[d] | 22[d] | 230 |
| Total PCBs | 130 | 2,500 | 130 | 3,100 |
| Phthalates | | | | |
| Dimethyl phthalate | 71 | 160 | 71 | 1,400[e] |
| Diethyl phthalate | 97 | 97 | 200 | 1,200[e] |
| Di-n-butyl phthalate | 1,400 | 5,100[e] | 1,400 | 5,100[e] |

TABLE 2. (Continued)

| Chemical | 1986 | | 1988 | |
|---|---|---|---|---|
| | LAET[b] | HAET[c] | LAET[d] | HAET[e] |
| **Phthalates (continued)** | | | | |
| Butyl benzyl phthalate | 63 | 470 | 63 | 900 |
| Bis(2-ethylhexyl)phthalate | 1,900 | 3,100[e] | 1,300[d] | 3,100[e] |
| Di-n-octyl phthalate | f | 69,000[e] | 6,200 | 6,200[d] |
| **Phenols** | | | | |
| Phenol | 420 | 1,200 | 420 | 1,200 |
| 2-Methylphenol | 63 | 72[e] | 63 | 72[e] |
| 4-Methylphenol | 670 | 1,200 | 670 | 3,600 |
| 2,4-Dimethyl phenol | 29 | 50[e] | 29 | 210 |
| Pentachlorophenol | f | f | 360 | 690 |
| **Miscellaneous Extractable Compounds** | | | | |
| Benzyl alcohol | 57 | 73 | 57 | 870 |
| Benzoic acid | 650 | 690[e] | 650 | 760 |
| Dibenzofuran | 540 | 540 | 540 | 1,700 |
| Hexachlorobutadiene | 120 | 290 | 11[d] | 270[d] |
| N-Nitrosodiphenylamine | 40 | 220 | 40 | 130[d] |
| **Volatile Organic Compounds** | | | | |
| Tetrachloroethene | 140 | 210[e] | 57[d] | 210[e] |
| Ethylbenzene | 33 | 50[e] | 10[d] | 50[e] |
| Total xylenes | 100 | 160[e] | 40[d] | 160[e] |
| **Pesticides** | | | | |
| p,p'-DDE | 9 | 15 | 9 | 15 |
| p,p'-DDD | 2 | 43 | 16 | 43 |
| p,p'-DDT | 3.9 | 11 | 34 | 270[e] |
| Aldrin | f | f | f | f |
| Chlordane | f | f | f | f |
| Dieldrin | f | f | f | f |
| Heptachlor | f | f | f | f |
| gamma-HCH (lindane) | f | f | f | f |

[a] HAET = Highest AET for a range of biological indicators; HAET = Lowest AET for a range of biological indicators; ">" indicates that for the AET and biological indicator establishing the LAET or HAET value, there were no "effects" stations with chemical concentrations above the highest concentration among "no effects" stations.

[b] 1986 LAET and HAET are the lowest and highest AET, respectively, established for four biological indicators in a 190-station database (see individual AET values in Table 1).

[c] 1988 LAET and HAET are the lowest and highest AET, respectively, established for four biological indicators in a 334-station database (see individual AET values in Table 2 presented in Barrick et al. 1988; Volume I).

TABLE 2. (Continued)

[d] The 1988 LAET or HAET value is lower than the corresponding 1986 value because of the implementation of guidelines for the treatment of anomalous biological and chemical data (see Section 2.4 in Barrick et al. 1988; Volume I).

[e] The HAET for these chemicals were established using a "greater than" value (see footnote **a**); such values were only used for chemicals that had at least one defined AET at a lower concentration than the "greater than" value shown.

[f] No defined AET are available for these chemicals (see footnote **a**).

## TABLE 3. SUMMARY OF SELECTED CHEMICAL CONCENTRATIONS AND KEY SEDIMENT CHARACTERISTICS FOR BIOLOGICAL STATIONS FROM REFERENCE AND NONREFERENCE AREAS OF PUGET SOUND[a]

| | Reference Area[b] | | Non-Reference Area[c] | |
|---|---|---|---|---|
| Chemical | Minimum | Maximum | Minimum | Maximum |
| **Metals** (mg/kg dry weight; ppm) | | | | |
| Antimony | 0.13 | 2.86 | 0.1 | 1,370 |
| Arsenic | 1.9 | 22 | 0.34 | 9,700 |
| Cadmium | 0.047 | 1.9 | 0.3 | 184 |
| Chromium | 9.6 | 255 | 5.4 | 555 |
| Copper | 4.9 | 74 | 3.6 | 11,400 |
| Lead | 0.4 | 23 | 0.79 | 71,100 |
| Mercury | 0.016 | 0.134 | 0.06 | 52 |
| Nickel | 11 | 141 | 6.9 | 118 |
| Silver | 0.02 | 0.78 | 0.013 | 8.27 |
| Zinc | 15 | 102 | 18.4 | 6,010 |
| **Organic Compounds** (ug/kg dry weight; ppb) | | | | |
| Low molecular weight PAH | 2.5 | 55 | 1.3 | 630,000 |
| High molecular weight PAH | 22 | 140 | 7.5 | 3,200,000 |
| 1,4-Dichlorobenzene | U 5 | U 160 | 1 | 31,000 |
| Hexachlorobenzene (HCB) | U 0.3 | U 800 | 0.05 | 730 |
| Hexachlorobutadiene | U 1.3 | U 820 | 1 | 730 |
| N-Nitrosodiphenylamine | U 5 | U 2,500 | 4 | 610 |
| 4-Methylphenol | 2 | 290 | 3 | 100,000 |
| Phenol | 13 | 560 | 0.9 | 2,900 |
| Total PCBs | 2.7 | 37 | 0.5 | 9,600 |
| **Conventional Sediment Variables** (dry weight) | | | | |
| Total organic carbon (%) | 0.19 | 2.69 | 0.06 | 29.4 |
| Fine-grained material (%) | 7.4 | 88 | 2.7 | 95.5 |
| Sulfides (mg/kg; ppm) | 2.2 | 31 | 1 | 7,610 |

---

[a] Ranges are based only on biological stations used in the evaluation of Puget Sound AET. Higher concentrations for some chemicals have been detected in sediment samples for which there are no biological data, including several samples collected at depth. "U" indicates undetected in all samples over the detection limit range shown; otherwise the minimum value is the lowest detected concentration and the maximum value is the highest detected concentration (detection frequencies are not indicated but are less that 100 percent for most chemicals except metals).

[b] Reference areas in Puget Sound are generally removed from the direct influence of contaminant sources in nonurbanized areas of the sound; almost all of these stations are nonimpacted.

[c] Most data for nonreference areas are from industrialized urban embayments; nonreference data include both nonimpacted and impacted stations.

## 2.3 SCREENING LEVEL AND MAXIMUM LEVEL VALUES

The SL and ML values reported by PSDDA in June, 1988 (Phillips et al. 1988) are listed in Table 4. The PSDDA definitions of SL and ML are summarized in the following sections.

### 2.3.1 Screening Levels

The SL for chemical testing is a guideline used to define the concentration of a chemical in dredged material below which there is no reason to believe that unacceptable adverse biological impacts would result from unconfined, open-water disposal. Dredged material that contains concentrations of chemicals of concern below SL is acceptable for unconfined, open-water disposal without biological testing. The rationale for the SL concept is discussed further by Phillips et al. (1988).

SL values developed by PSDDA are set relative to sediment quality values as follows:

Screening Level = 10 percent of the ML set for unconfined, open-water disposal, provided;
(a) the value equals or exceeds the average concentration for the chemical in Puget Sound reference areas, and
(b) the value is less than the lowest AET (LAET) determined for a range of biological indicators.

Exceptions to this definition for SL values were made for the following special cases (Phillips et al. 1988):

- For chemicals for which there was no defined 1986 AET for any biological indicator (e.g., pentachlorophenol and 1,3-dichlorobenzene in Table 1), no maximum level value was established and the SL value was set equal to the preliminary AET.

- For hexachloroethane and trichloroethene, AET values were not available and SL values for these chemicals were established as 10 percent of the ML set using the Equilibrium Partitioning approach (described in Beller et al. 1986).

- For phthalate esters, the SL value was set equal to the highest AET for a range of biological indicators because phthalates are common laboratory contaminants and reliable analyses for these chemicals are difficult. A higher screening level was considered appropriate so that biological testing would not be triggered, and material would not be labeled unacceptable for disposal, solely by the routine presence of detectable levels of phthalates.

- For pesticides, the SL value was set approximately equal to the limit of quantification established as 5 times the instrument detection limit. Though often not detected in Puget Sound sediments, certain pesticides are known to occur in the upper reaches of navigable waterways that drain agricultural river basins. The SL values for pesticides are comparable

## TABLE 4. SCREENING AND MAXIMUM LEVEL CHEMISTRY VALUES USED IN THE PSDDA PROGRAM

| Chemical | SL[*] | ML[*] |
|---|---|---|
| **Metals** (mg/kg dry weight; ppm) | | |
| Antimony | 2.6 | 26 |
| Arsenic | 70 | 700 |
| Cadmium | 0.96 | 9.6 |
| Copper | 81 | 810 |
| Lead | 66 | 660 |
| Mercury | 0.21 | 2.1 |
| Nickel | 28 | 120[a] |
| Silver | 1.2 | 5.2 |
| Zinc | 160 | 1,600 |
| **Organic Compounds** (ug/kg dry weight; ppb) | | |
| Low molecular weight PAH | 610 | 6,100 |
| Naphthalene | 210 | 2,100 |
| Acenaphthylene | 64 | 640 |
| Acenaphthene | 63 | 630 |
| Fluorene | 64 | 640 |
| Phenanthrene | 320 | 3,200 |
| Anthracene | 130 | 1,300 |
| 2-Methylnaphthalene | 67 | 670 |
| High molecular weight PAH | 1,800 | 51,000[a] |
| Fluoranthene | 630 | 6,300 |
| Pyrene | 430 | 7,300[a] |
| Benz(a)anthracene | 450 | 4,500 |
| Chrysene | 670 | 6,700 |
| Benzofluoranthenes | 800 | 8,000 |
| Benzo(a)pyrene | 680 | 6,800 |
| Indeno(1,2,3,-c,d)pyrene | 69 | 5,250[a] |
| Dibenzo(a,h)anthracene | 120 | 1,200 |
| Benzo(g,h,i)perylene | 540 | 5,400 |
| Chlorinated Benzenes | | |
| 1,3-Dichlorobenzene | 170 | [b] |
| 1,4-Dichlorobenzene | 26 | 260 |
| 1,2-Dichlorobenzene | 19[c] | 50[a] |
| 1,2,4-Trichlorobenzene | 6.4 | 64 |
| Hexachlorobenzene | 23 | 230 |
| Total PCBs | 130 | 2,500 |
| Phthalates[c] | | |
| Dimethyl phthalate | 160[d] | [d] |
| Diethyl phthalate | 97[d] | [d] |
| Di-n-butyl phthalate | 1,400[d] | [d] |

**TABLE 4. (Continued)**

| | | |
|---|---|---|
| Phthalates (continued) | | |
| Butyl benzyl phthalate | 470[d] | [d] |
| Bis(2-ethylhexyl)phthalate | 3,100[d] | [d] |
| Di-n-octyl phthalate | 69,000[d] | [d] |
| Phenols | | |
| Phenol | 120 | 1,200 |
| 2-Methylphenol | 10 | 72[a] |
| 4-Methylphenol | 120 | 1,200 |
| 2,4-Dimethyl phenol | 10[c] | 50 |
| Pentachlorophenol | 140 | [b] |
| Miscellaneous Extractable Compounds | | |
| Benzyl alcohol | 10[c] | 73 |
| Benzoic acid | 216[c] | 650[a] |
| Dibenzofuran | 54 | 540 |
| Hexachloroethane | 1,400[f] | 14,000[e] |
| Hexachlorobutadiene | 29 | 290 |
| N-Nitrosodiphenylamine | 22 | 220 |
| Volatile Organic Compounds | | |
| Trichloroethene | 160[f] | 1,600[e] |
| Tetrachloroethene | 14 | 210[a] |
| Ethylbenzene | 10 | 50[a] |
| Total xylenes | 12 | 160[a] |
| Pesticides | | |
| Total DDT | 6.9 | 69 |
| Aldrin | 5[g] | [g] |
| Chlordane | 5[g] | [g] |
| Dieldrin | 5[g] | [g] |
| Heptachlor | 5[g] | [g] |
| Lindane | 5[g] | [g] |

Source: June 1988 SL and ML values from Phillips et al. 1988.

[a] The following procedures were used to develop SL and ML for the recommended effects level:

SL = 10% of ML or average reference area concentration, whichever is higher, but never greater than the lowest AET for a range of biological indicators.

ML = Highest Apparent Effects Threshold value (HAET) for a range of biological indicators.

TABLE 4. (Continued)

[a] PSDDA has adjusted the ML upward for this chemical to account a biological indicator which was represented by a "greater than" value for the AET. Such values indicate that a defined AET could not be established because there were no "effects" stations with chemical concentrations above the highest concentration among "no effects" stations for that biological indicator (see Appendix A).

[b] No ML is currently available for these compounds because there were no defined AET for any biological indicator (see discussion of "greater than" values in footnote **a**). PSDDA may assign ML values as in footnote **a**.

[c] For these compounds, the reference concentration was higher than the calculated value of SL, so SL was set at the average reference value.

[d] In PSDDA, biological testing is not triggered solely by the presence of phthalates. Because these compounds are often present as laboratory contaminants, the highest AET was used as the screening level and no maximum levels were set.

[e] These ML were set using the Equilibrium Partitioning approach (see Beller et al. 1986) because no AET values were available.

[f] For chemicals with ML values set by the Equilibrium Partitioning approach, SL was still calculated according to the formulas given above.

[g] SL for these pesticides was set to 5 times an assumed analytical detection limit of 1 ug/kg dry weight sediment. No sediment quality values were available for setting maximum levels; changes to these values are still under consideration by PSDDA.

to the low pesticide concentration seen in Puget Sound reference area sediments (1 to 3 ug/kg dry weight) and were also considered consistent with guidance from the American Chemical Society on reliable data reporting.

### 2.3.2 Maximum Levels

ML values developed by PSDDA correspond to the concentration of a chemical in dredged material above which there is "reason to believe" that the material would cause significant adverse biological effects to different biological organisms and would therefore be unsuitable for unconfined, open-water disposal. For sediments contaminated at concentrations above the ML, the dredger can accept the indication of the chemical ML values that the material is unacceptable for unconfined, open-water disposal, or the dredger can conduct optional biological testing to establish the acceptability of the material (Phillips et al. 1988). Between the SL and ML, biological testing for a range of indicator bioassays is always required.

For optional biological testing above the ML, the dredger would conduct both the standard bioassays (five acute bioassays and bivalve bioaccumulation) and other additional, more sensitive sublethal tests in order to determine final biological acceptability of the material for unconfined, open-water disposal. Appropriate biological tests and test interpretation would be determined by the PSDDA agencies on a project-by-project basis. If the project material meets the test requirements, the dredged material will be considered acceptable for unconfined, open-water disposal.

ML values used by PSDDA to manage unconfined, open-water disposal sites are set equal to the HAET for a range of biological indicators. The rationale for use of the ML concept is further discussed by Phillips et al. (1988). The HAET for some chemicals is based on a preliminary AET value [e.g., the benthic AET for high molecular weight polynuclear aromatic hydrocarbons (HPAH) is >51,000 parts per billion (ppb) and is the highest of the AET for HPAH in Table 1]. This qualifier indicates that for the biological indicator setting the HAET, there were no impacted stations exhibiting sediment concentrations of the chemical higher than the "greater than" value set by a nonimpacted station. ML values have been adjusted to reflect these preliminary AET values (Phillips et al. 1988) because the purpose of the ML is to efficiently identifying only stations with actual impacts. ML values that have been adjusted by PSDDA (e.g., the benthic AET for HPAH of >51,000 was used to approximate a ML value for HPAH) are identified in Table 4 (see footnote **a**).

## 2.4 DATA SETS USED FOR ANALYSES

A total of 11 data sets were used to evaluate PSDDA SL and ML values. The data were collected from both contaminated and relatively uncontaminated areas of Puget Sound, including urban and nonurban areas and most of the major dredging areas in the central part of the estuary.

PSDDA SL and ML values are primarily based on Puget Sound AET (see footnote e in Table 3 for exceptions). These AET are based on data collected in eight Puget Sound surveys (Figure 3 and Table 5). Additional data sets used to test the predictive capability of SL and ML include amphipod bioassay and/or benthic infaunal analyses conducted for studies at Eagle Harbor (10 stations), Elliott Bay (74 benthic infauna

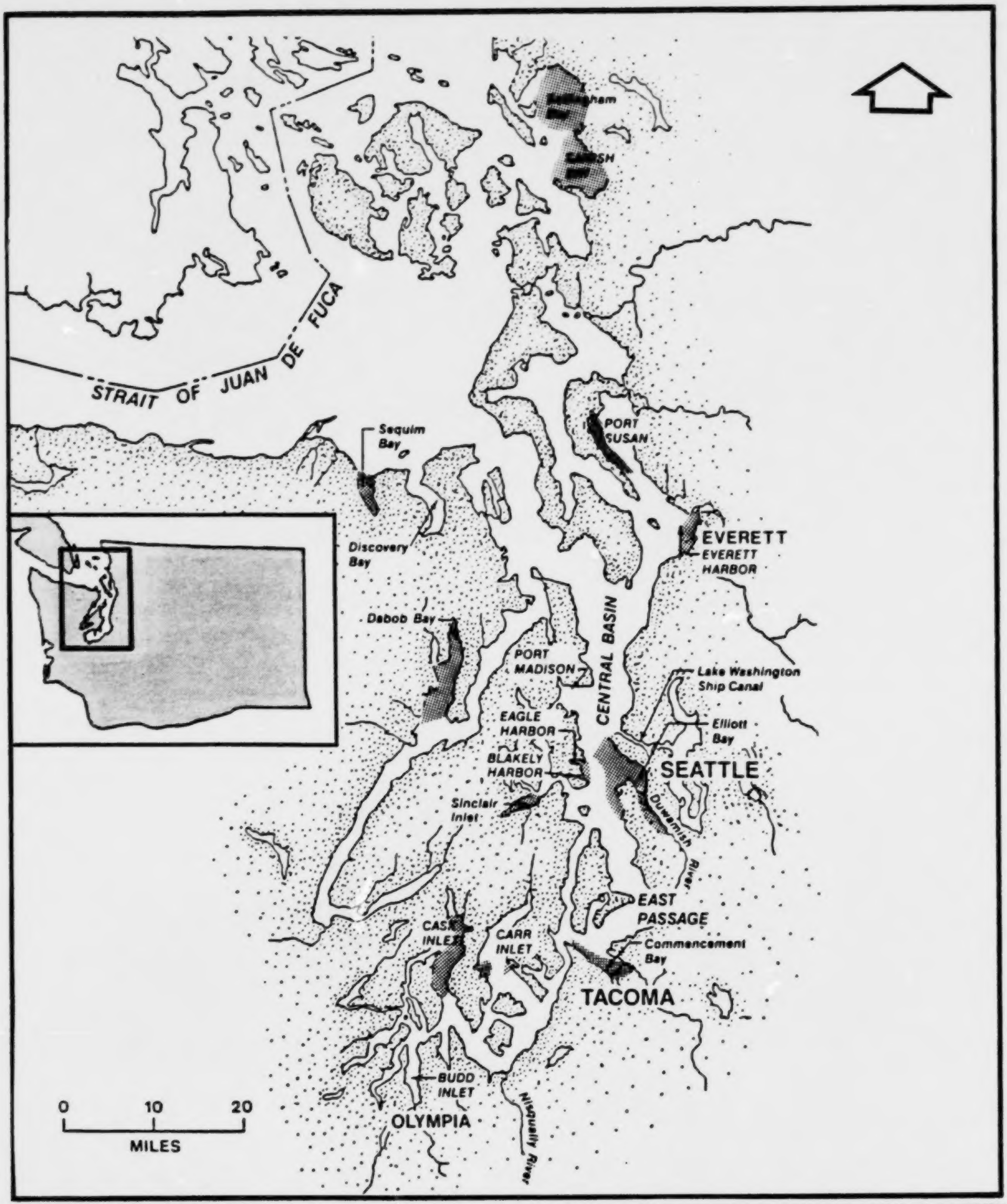

Bellingham Bay
SAMISH Bay
STRAIT OF JUAN DE FUCA
Sequim Bay
PORT SUSAN
Discovery Bay
EVERETT
EVERETT HARBOR
Dabob Bay
PORT MADISON
CENTRAL BASIN
Lake Washington Ship Canal
EAGLE HARBOR
Elliott Bay
BLAKELY HARBOR
SEATTLE
Sinclair Inlet
Duwamish River
EAST PASSAGE
CASE INLET
CARR INLET
Commencement Bay
TACOMA
BUDD INLET
0
10
20
MILES
OLYMPIA
Nisqually River

Figure 3. Location of sampling sites for Apparent Effects Threshold data sets.

## TABLE 5. SUMMARY OF DATA SETS USED TO EVALUATE PSDDA SCREENING LEVEL AND MAXIMUM LEVEL VALUES

| Embayment | Survey Code | Number/Kind of Bioeffect Samples[a] | Chemical Analyses Conducted[b] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Acid | Base | Neut. | PCB | Pest. | VOA | Metal | Misc |
| Bellingham Bay | EIGHTBAY | 8 / A | x | x | x | x | x | x | x | |
| Carr Inlet | CBMSQS | 4 / BAOM | x | x | x | x | x | x | x | x |
| Case Inlet | EIGHTBAY | 4 / A | x | x | x | x | x | x | x | |
| Central Puget Sound Basin | ALKI | 4 / B | x | x | x | x | x | x | x | |
| | EHCHEM | 2 / BA | x | x | x | x | x | x | x | x |
| Commencement Bay | CBBLAIR | 6 / BAO | x | x | x | x | x | x | x | x |
| | CBMSQS | 42 / BAOM | x | x | x | x | x | x | x | x |
| | | 2 / AOM | | | | | | | | |
| | | 2 / B OM | | | | | | | | |
| Dabob Bay | EIGHTBAY | 4 / A | x | x | x | x | x | x | x | |
| Eagle Harbor | EHCHEM | 8 / BA | x | x | x | x | x | x | x | x |
| Elliott Bay | EBCHEM | 71 / BA | x | x | x | x | x | x | x | x |
| | | 24 / A | | | | | | | | |
| | | 4 / B | | | | | | | | |
| | ALKI | 7 / B | x | x | x | x | x | x | x | |
| | TPPS3AB | 27 / B | x | x | x | x | x | x | x | |
| | DUWRIV1 | 8 / A | | | x | x | x | x | x | |
| | DUWRIV2 | 30 / A | | | x | x | x | x | x | |
| | EIGHTBAY | 8 / A | x | x | x | x | x | x | x | |
| Everett Harbor | EVCHEM | 13 / BA | x | x | x | x | x | x | x | x |
| | | 13 / A | | | | | | | | |
| | | 3 / B | | | | | | | | |
| | EVERETT1 | 6 / A | | x | x | | x | x | | |
| | EIGHTBAY | 8 / A | x | x | x | x | x | x | x | |
| Port Susan | EBCHEM | 5 / BA | x | x | x | x | x | x | x | x |
| | EVCHEM | 3 / BA | x | x | x | x | x | x | x | x |
| Samish Bay | EIGHTBAY | 4 / A | x | x | x | x | x | x | x | |
| Sequim Bay | EIGHTBAY | 4 / A | x | x | x | x | x | x | x | |
| | DUWRIV1 | 1 / A | | | x | x | x | x | x | |
| | DUWRIV2 | 1 / A | | | x | x | x | x | x | |
| Sinclair Inlet | EIGHTBAY | 8 / A | x | x | x | x | x | x | x | |

**TABLE 5. (Continued)**

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[a] 334 distinct samples (including 12 repeated samplings) at a total of 322 locations: (B) 201 benthic infaunal analyses; (A) 287 amphipod mortality bioassays; (O) 56 oyster larvae abnormality bioassays; (M) 50 Microtox (saline extract) bioassays. The seven amphipod bioassay stations excluded as biological anomalies, and four benthic infauna and eight amphipod bioassay stations excluded as chemical anomalies (see Section 2.4 and Appendix C) are not included in these totals. Station locations for each survey are summarized in Appendix B.

[b] Chemical analyses conducted for U.S. EPA priority pollutant acid, base, neutral, PCB, pesticide, and volatile organic compounds, metals, and miscellaneous compounds not recognized as EPA priority pollutants (e.g., resin acid compound data for the EVCHEM survey, and tentatively identified organic compounds).

stations and 99 amphipod bioassay stations), and Everett Harbor (21 benthic infauna stations and 28 amphipod bioassay stations). A list of stations and biological test types for these new studies is also provided in Table 5.

A summary of data sources used in this project is provided in Appendix B. Location maps of all stations are given in Figures B-1 through B-20. Data tables produced from SEDQUAL for PSDDA SL and ML comparisons are provided in Appendix C.

# 3. RESULTS

## 3.1 EVALUATION OF THE SENSITIVITY OF PSDDA SCREENING LEVEL VALUES

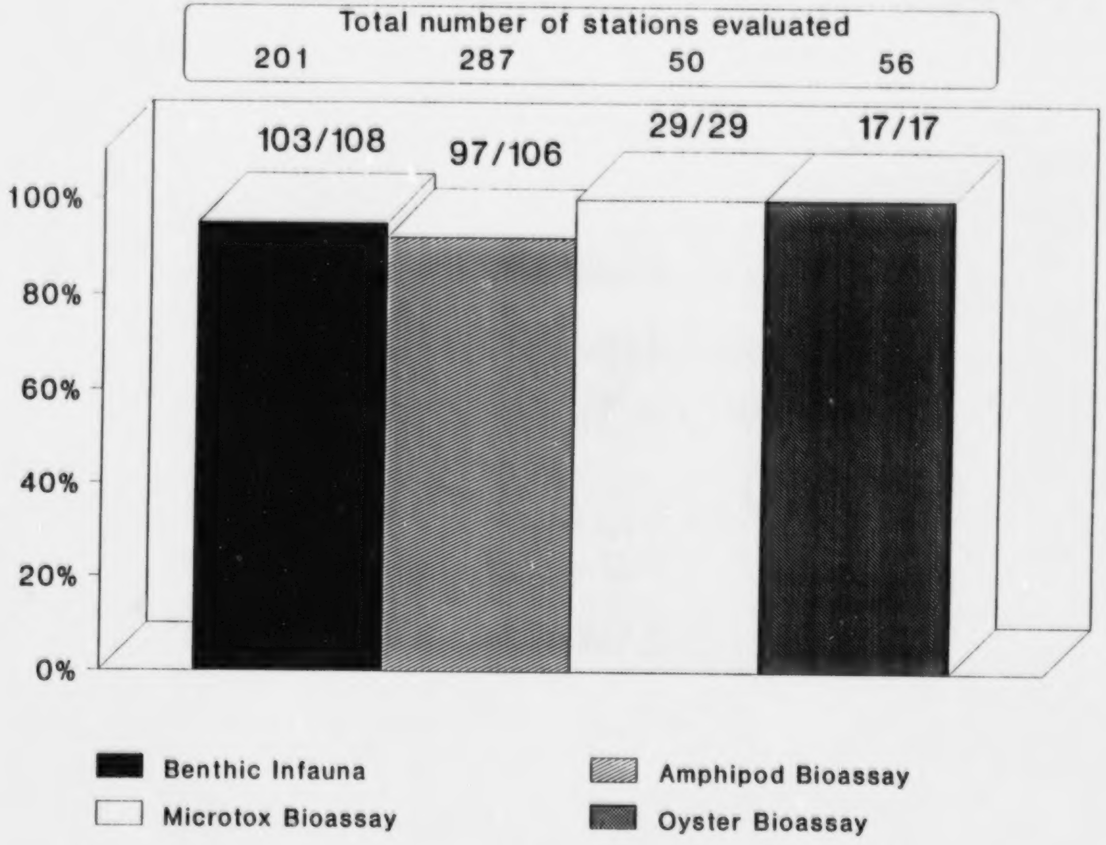
PSDDA SL values (Phillips et al. 1988) were applied to the entire 11-survey Puget Sound database (Table 5) to evaluate their predictive sensitivity. These evaluations were made relative to the PSDDA objective of not allowing exceedance of "minor adverse biological effects" at Puget Sound dredged disposal sites. The purpose of the evaluations was to determine the degree to which the SL values are defensibly "safe" (e.g., fully protective of observed biological effects). Sensitive SL values should identify all biologically impacted stations when used to predict which sediments should undergo definitive screening by biological tests. Sensitivity was used as the primary measure of the reliability of SL values because sensitivity, not efficiency, focuses on the ability to identify all impacted stations. Although not specifically addressed as an objective of this evaluation, the efficiency of SL values is also summarized in this section.

Depending on the biological indicator, PSDDA SL values were 94 to 100 percent sensitive in identifying all impacted stations in the database (Figure 4). Stations at which chemical concentrations did not exceed any SL but exhibited statistically significant ($P<0.05$) adverse effects are identified in Table 6. Such stations are noteworthy because SL values do not exceed the lowest AET for any of the biological indicators used to establish AET, and hence are not expected to exhibit adverse effects. Chemical and biological data for each of these stations were reviewed to assess possible reasons for the apparently incorrect predictions, including the following:

- The indicated adverse biological effect resulted from factors other than toxic chemical exposures (e.g., physical disruption, grain size distribution)
- Unidentified chemicals accounted for the sediment toxicity
- High chemical detection limits precluded an assessment of whether the SL was exceeded
- The biological effect was incorrectly classified as significant because of a Type I statistical error.

All stations exhibiting adverse effects according to the Microtox or oyster larvae abnormality bioassays exceeded the PSDDA SL values. SL values were not exceeded at 5 of 108 impacted benthic infaunal stations and 9 of 106 impacted amphipod bioassay stations (Figure 4 and Table 6). These impacted stations exhibited one or more of the following physical or chemical characteristics:

- With one exceptions, the impacted benthic infauna stations were highly coarse-grained (>75 percent) and, with four exceptions, the impacted amphipod bioassay were highly fine-grained (>75 percent)
- Higher-than-normal detection limits (e.g., especially for chlorinated aromatic hydrocarbons and phenols) precluded comparisons with screening



$$\% \text{ Sensitivity} = \frac{\text{Number of stations exceeding SL value}}{\text{Number of impacted stations}} \times 100$$

Figure 4. Sensitivity of PSDDA screening level values

## TABLE 6. STATIONS NOT EXCEEDING PSDDA SCREENING LEVEL VALUES, BUT EXHIBITING AT LEAST ONE ADVERSE BIOLOGICAL EFFECT

| Embayment | Survey | Station | Biological Tests[a] | Key Distinguishing Factors |
|---|---|---|---|---|
| | | **Significant Benthic Impacts** | | |
| Everett | EVCHEM | SD-01 | A, B* | % coarse[d] = 95.5 |
| Elliott | EBCHEM | AB-03 | A, B* | DL[e]; % coarse= 95.3 |
| | | MG-03 | A, B* | DL ; % coarse = 77.5 |
| | | MG-04 | A, B* | DL (% coarse = 14.3) |
| | TPPS3AB (7/15/82) | WP-03 | B* | DL ; % coarse = 95.3 |
| | | **Significant Amphipod Mortality** | | |
| | DUWRIV1 | DR-07 | A* | no obvious factors[b] (% fines[c] = 53.8) (all PSDDA chemicals not analyzed) |
| | DUWRIV2 | DR-16 | A* | no obvious factors (% fines = 37.9) (all PSDDA chemicals not analyzed) |
| Dabob | EIGHTBAY | DB-07 | A* | DL (% fines = 49) |
| | | DB-15 | A* | DL ; % fines = 89.7 |
| Case | EIGHTBAY | CS-11 | A* | DL (% fines = 39) |
| Samish | EIGHTBAY | SM-01 | A* | DL ; % fines = 81.2 |
| | | SM-03 | A* | DL ; % fines = 80.9 |
| | | SM-07 | A* | DL ; % fines = 84.9 |
| | | SM-20 | A* | DL ; % fines = 87.3 |

NOTE: Asterisk (*) indicates statistically significant ($P<0.05$) adverse effect. (i.e., amphipod mortalities at Stations AB-03, MG-03, MG-04, and SD-01 were not statistically significant but benthic infaunal abundances at these stations were statistically significant)

[a] A = Amphipod mortality bioassay.
B = Benthic infaunal analysis.

[b] However, all PSDDA chemicals of concern were not analyzed in the DUWRIV1 and DUWRIV2 surveys.

[c] Percent fine-grained material (i.e., <63 micron).

[d] Percent coarse-grained material (i.e., >= 63 micron).

[e] DL = Detection limits of at least one chemical exceeded the SL value for that chemical.

level values at 11 of the 14 stations, including all of the EIGHTBAY stations in Table 6.

- Polar organic chemicals (e.g., phenols) were not analyzed at some of these stations (e.g., stations from Surveys DUWRIV1 and DUWRIV2; see Table 5); in other cases, chemicals were detected for which SL have not been established (e.g., chlorinated resin acids detected at Station SD-01 in Everett Harbor).

Sediments at four of the five stations exhibiting significant depressions in benthic infaunal abundances contained from 77 to 95 percent coarse-grained material. The grain size distribution at stations at which PSDDA SL values correctly predicted adverse benthic impacts spanned a much wider range from 4 to 97 percent coarse grained-material; two thirds of the correctly predicted benthic stations contained <75 percent coarse-grained material. Grain size distribution is typically factored into the comparison of benthic results to reference conditions, although low benthic infaunal abundances at coarse-grained stations could result from inadequate colonization conditions that are not accounted for at reference area stations.

It should be noted that benthic analyses for the Elliott Bay and Everett Harbor surveys were not stratified by grain size for reference area comparison (Beller et al. 1988; Pastorok et al. 1988). The reference data from Port Susan indicated no obvious change in abundance for sediment types covering the range of grain size in Elliott Bay. However, the benthic communities at the two Magnolia Bluff stations from the Elliott Bay survey (Table 6) likely differ from reference conditions in Port Susan, because the two areas are exposed to substantially different wave regimes (i.e., the Port Susan stations are in a protected bay and Magnolia stations are on an exposed beach) (Beller et al. 1988). In addition, there were enhancements rather than depressions in the abundance of crustaceans at the Magnolia stations, although crustaceans generally exhibit lower abundances in response to toxic chemical exposures and environmental stress (Reish and Barnard 1979; Swartz et al. 1985). In no case were the apparent adverse benthic effects shown in Table 6 corroborated by independent amphipod bioassay results (amphipod bioassay results were not available for one of the five stations), although these two indicators are not expected to be perfectly correlated.

Sediments at five of the nine stations exhibiting significant amphipod mortality contained a high percentage of fine-grained material, a condition that may influence the percent mortality of these organisms (DeWitt et al. 1988). Amphipods normally prefer coarse-grained environments. The grain size distribution at the other four stations was not remarkable (the samples contained 39 to 49 percent fine-grained material). High detection limits precluded evaluation of all chemicals at two of these stations from the EIGHTBAY survey. There were no obvious factors contributing to the observed amphipod mortality at the remaining two stations from Duwamish River dredged material characterization studies, although concentration data were not available for all PSDDA chemicals of concern (Table 5). The grain size distribution at stations at which PSDDA SL values correctly predicted amphipod mortality spanned a much wider range from 3 to 97 percent fine grained-material; 62 percent of the correctly predicted benthic stations contained <75 percent fine-grained material.

The 2-3 highest concentrations of chemicals at the 14 stations in Table 6 relative to PSDDA SL values are summarized in Table 7. In most cases, metals were present in highest concentration relative to PSDDA SL values. Detected chemicals were typically

## TABLE 7. SELECTED CHEMICAL CONCENTRATIONS AT STATIONS NOT EXCEEDING PSDDA SCREENING LEVELS, BUT EXHIBITING ADVERSE BIOLOGICAL EFFECTS

| Station | Chemical | Concentration | Qualifier[a] | Percentage of PSDDA SL Value[b] |
|---|---|---|---|---|
| | **DUWRIV1 and DUWRIV2 Surveys (Duwamish River)** | | | |
| DR-07 | PCBs | 120 ppb | | 92 % |
| | indeno(c,d)pyrene | 59 ppb | | 86 % |
| | HPAH | 1,400 ppb | | 78 % |
| DR-16 | mercury | 0.14 ppm | | 67 % |
| | copper | 20 ppm | | 25 % |
| | zinc | 34 ppm | | 21 % |
| | **EBCHEM Survey (Elliott Bay)** | | | |
| AB-03 | dibenzofuran | 14 ppb | E | 26 % |
| | zinc | 37 ppm | E | 23 % |
| MG-03 | zinc | 42 ppm | E | 26 % |
| | lead | 14 ppm | | 20 % |
| MG-04 | mercury | 0.19 ppm | E | 90 % |
| | zinc | 33 ppm | E | 21 % |
| | **EIGHTBAY Survey (Puget Sound)** | | | |
| CS-11 | cadmium | 0.6 ppm | | 63 % |
| | copper | 30 ppm | | 37 % |
| DB-07 | silver | 0.78 ppm | | 65 % |
| | copper | 50 ppm | | 62 % |
| | zinc | 86 ppm | | 54 % |
| DB-15 | copper | 74 ppm | | 93 % |
| | zinc | 100 ppm | | 63 % |
| SM-01 | bis(2-ethylhexyl)phthalate | 2,800 ppb | | 90 % |
| | phenanthrene | 170 ppb | | 53 % |
| SM-07 | zinc | 76 ppm | | 48 % |
| | copper | 33 ppm | | 41 % |
| | mercury | 0.07 ppm | | 33 % |
| SM-03 | copper | 40 ppm | | 49 % |
| | zinc | 75 ppm | | 47 % |
| SM-20 | zinc | 81 ppm | | 51 % |
| | copper | 40 ppm | | 50 % |

TABLE 7. (Continued)

| Station | Chemical | Concentration | Qualifier[a] | Percentage of PSDDA SL Value[b] |
|---|---|---|---|---|
| | **EVCHEM Survey (Everett Harbor)** | | | |
| SD-01 | N-nitrosodiphenylamine | 15 ppb | E | 68 % |
| | zinc | 52 ppm | | 33 % |
| | **TPPS3AB Survey (West Point)** | | | |
| WP-03 | pyrene | 140 ppb | | 33 % |
| (7/15/82) | HPAH | 450 ppb | | 25 % |

[a] E = estimated value; L = estimated concentration is less than value shown.

[b] Percentages of PSDDA SL values are listed for selected chemicals present at the highest concentrations relative to SL values.

present at less than 80 percent of SL values (in three cases, less than 34 percent). In all cases, the SL values for the chemicals shown in Table 7 are less than the lowest of the corresponding 1986 AET shown in Table 1. Although undetected or unmeasured chemicals may account for some of these mispredicted stations, there is stronger and generally consistent evidence for physical factors (e.g., grain size; habitat exposure) contributing to the apparent adverse biological effects at most of these stations.

A comparison of the predictive sensitivity and efficiency of PSDDA SL values for different geographic areas is presented in Figure 5. With the exception of the three Elliott Bay stations (EBCHEM survey) and one Everett Harbor station (EVCHEM survey) discussed previously (Table 6), the PSDDA SL is sensitive in detecting problem stations based on benthic infauna abundance for new surveys in Eagle Harbor, Everett Harbor, and Elliott Bay. Because of the large area encompassed by the Elliott Bay survey, the average for Elliott Bay is shown in Figure 5 as well as results for the East and West Waterways at the mouth of the Duwamish River (16 and 19 stations, respectively), North Harbor Island area (11 stations) on Elliott Bay, the Seattle South Waterfront (11 stations) along Elliott Bay, and the upper Duwamish River (16 stations). The efficiency of SL predictions at benthic infaunal stations ranges from approximately 45 to 95 percent for the new studies. The highest efficiency was determined for stations in the West Waterway and the area north of Harbor Island along Elliott Bay. The lowest efficiency was determined for stations along the Seattle South Waterfront.

The PSDDA SL values are 100 percent sensitive in identifying problem stations indicated by the amphipod bioassay for the new surveys in Eagle Harbor, Everett Harbor, and most areas of Elliott Bay (Figure 5). The efficiency of these predictions is more variable than that for benthic infaunal stations. The lowest efficiency was determined for stations in Eagle Harbor. The amphipod bioassay is relatively insensitive to hydrocarbon contamination, which is the primary type of contamination in Eagle Harbor, compared to the other biological indicators tested in Puget Sound. The highest efficiency of predictions by PSDDA SL values was found in the upper Duwamish River, the East Waterway of the Duwamish River, and the adjacent area north of Harbor Island along Elliott Bay.

## 3.2 EVALUATION OF THE EFFICIENCY OF PSDDA MAXIMUM LEVEL VALUES

PSDDA ML values (Phillips et al. 1988) were applied to the Eagle Harbor, Elliott Bay, and Everett Harbor data sets to evaluate the predictive efficiency of the ML values. The overall efficiency of the ML values using the entire Puget Sound database was also evaluated. The purpose of these evaluations is to determine the degree to which the ML values are defensibly "not safe" without requiring biological testing (e.g., efficient, not overly protective, cost-effective in sediment management decisions). Efficient ML values should identify only biologically impacted stations when used to predict problem sediments (in PSDDA, biological testing is used to confirm biological effects in the concentration range between the SL and ML). To be highly efficient, ML are not expected to be sensitive in identifying all potential biological effects. Hence, efficiency was used as the primary measure of the reliability of ML values because efficiency, not sensitivity, focuses on the ability of a sediment quality value to identify only impacted stations. Although not specifically addressed as an objective of this evaluation, the sensitivity of ML values is also summarized in this section.

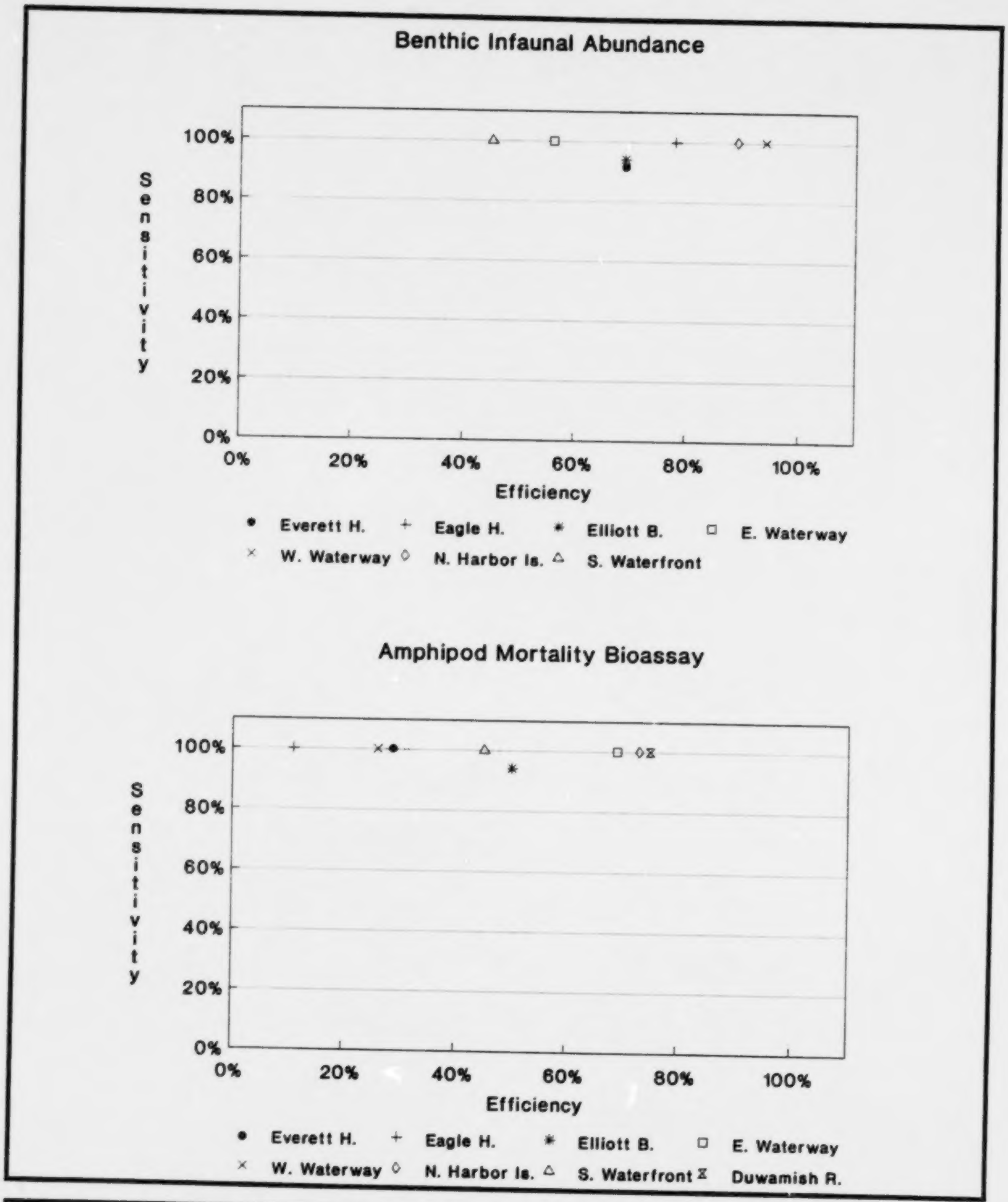


Figure 5. Comparison of the sensitivity and efficiency of PSDDA screening level values in Eagle Harbor, Everett Harbor, and Elliott Bay, and selected geographic areas of Elliott Bay

Depending on the biological indicator, PSDDA ML values were 77 to 100 percent efficient in identifying only impacted stations in the database (Figure 6). Efficiencies of 100 percent were obtained for the Microtox and oyster larvae bioassay stations because all nonimpacted stations for these biological indicators were included in the calculation of AET upon which the PSDDA ML are based. Hence, the predictive efficiency of these two indicators has not been clearly established.

Stations at which chemical concentrations exceeded ML, but for which at least one biological indicator did not exhibit statistically significant ($P \geq 0.05$) adverse effects, are shown in Table 8. The number of chemicals exceeding ML at these 16 stations (and four additional nonimpacted stations exhibiting anomalously high chemical concentrations; see footnote c) is also shown. At four of these stations (Stations NG-10, NG-14, KG-09, and WW-19), only a single chemical exceeded ML by less than a factor of two (Tables 8 and 9) and therefore the stations would be excepted according to the PSDDA single chemical exclusion rule (Phillips et al., 1988). The four stations at which both biological indicators were mispredicted (i.e., ML were exceeded but neither amphipod mortality nor depressions in benthic infaunal abundances were statistically significant) represent less than two percent of the Puget Sound database.

Because ML values generally equal the HAET for a range of biological indicators (Tables 1 and 2), all biological tests are expected to result in adverse effects at sediment concentrations above ML. For the incorrectly predicted stations in Table 8, at least one significant adverse effect was observed in over 70 percent (10 of 14) of the cases in which results for two biological indicators were available. Hence, such stations are correctly predicted by ML values to be adversely impacted according to at least one biological indicator, but there is not a preponderance of evidence by all indicators.

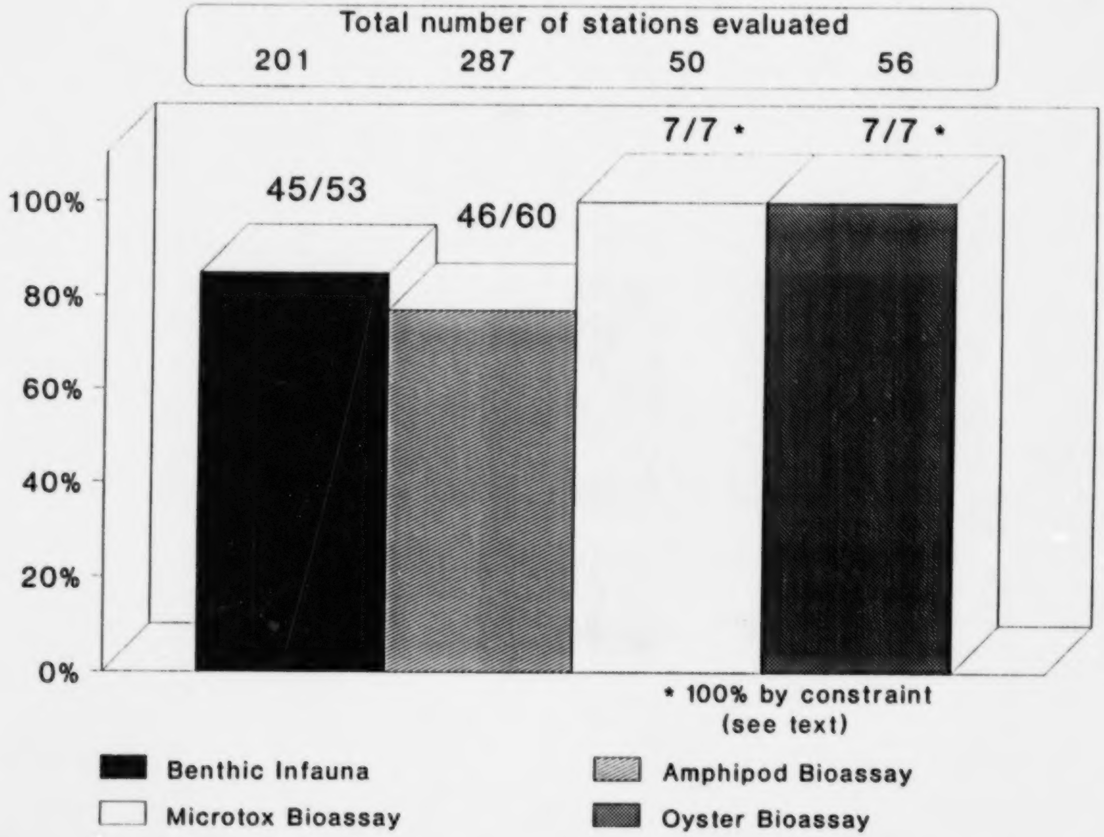
Chemical and biological data for each station in Table 8 (including the four stations listed in footnote c) were reviewed to assess possible reasons for the apparent mispredictions, including the following:

- Sediment quality values for some chemicals may not be adequately representative of contaminated conditions in Puget Sound [e.g., the AET approach assumes a wide range of chemical concentrations and biological effects in the data set establishing appropriate AET (Beller et al. 1986)].

- Chemical associations at some stations may result in reduced chemical exposure to organisms (i.e., higher sediment concentrations may be tolerated by organisms) that is not predicted by existing sediment quality values.

- Inadequate statistical power is achieved to distinguish adverse effects relative to reference conditions, especially in cases of elevated natural or laboratory variability for the biological test or suboptimal reference conditions (this latter factor is specifically addressed in Appendix C of Barrick et al. 1988; Volume I).

The concentrations of chemicals and factors by which PSDDA ML values are exceeded at these stations are presented in Table 9. PAH most frequently exceed PSDDA ML values at these stations (12 of 20 stations). Chemical concentrations at 40 percent (8 of 20 stations) of these stations were within a factor of two of the PSDDA ML values. The concentration of a single chemical exceeds corresponding ML values



$$\% \text{ Efficiency} = \frac{\text{Number of stations correctly predicted by ML value}}{\text{Number of stations predicted to be impacted}} \times 100$$

Figure 6. Efficiency of PSDDA maximum level values

## TABLE 8. NUMBER OF CHEMICALS EXCEEDING PSDDA MAXIMUM LEVEL VALUES AT STATIONS NOT EXHIBITING ALL ADVERSE BIOLOGICAL EFFECTS TESTED

| Survey | Station | Biological Effect[a] | Number of Chemicals Exceeding ML Values[b] |
|---|---|---|---|
| **No Amphipod or Benthic Effects** | | | |
| EBCHEM[c] (Elliott Bay) | EW-12 | A, B | 1 |
| | EW-14 | A, B | 10 |
| | SS-05 | A, B | 8 |
| EVCHEM (Everett Harbor) | NG-10 | A, B | 1[d] |
| **No Amphipod Effects (Benthic Effects Not Tested)** | | | |
| EVCHEM | ES-03 | A | 2 |
| | NG-14 | A | 1[d] |
| **Amphipod Effects But No Benthic Effects** | | | |
| EBCHEM | KG-09 | A*, B | 1[d] |
| | NS-07 | A*, B | 2 |
| | SS-07 | A*, B | 13 |
| **Benthic Effects But No Amphipod Effects** | | | |
| EBCHEM | KG-06 | A, B* | 2 |
| | WW-04 | A, B* | 9 |
| | WW-06 | A, B* | 1[d] |
| | WW-19 | A, B* | 2 |
| EHCHEM (Eagle Harbor) | EH-05 | A, B* | 2 |
| | EH-15 | A, B* | 9 |
| EVCHEM | EW-12 | A, B* | 1 |

NOTE: Asterisk (*) indicates a statistically significant ($P<0.05$) adverse effect; 10 of the 14 stations for which both biological indicators were available exhibited either significant amphipod mortality or depressions in the abundance of benthic infauna. Hence, for these 10 stations, the ML was efficient in predicting an adverse effect.

[a] A = Amphipod mortality bioassay; B = Benthic infaunal analysis.

[b] See listing of chemicals in Table 9.

TABLE 8. (Continued)

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[c] Chemical concentrations at four additional stations in the original EBCHEM survey also exceeded ML values, but at least one of these concentrations is considered anomalous with respect to those at other nonimpacted stations (i.e., greater than a factor of 3 times the concentration at any other nonimpacted effect station; see Section 2.4 in Barrick et al. 1988; Volume I). Three of these chemically anomalous stations also exhibited at least one significant biological effect and are listed below (shown in the same format for biological effects and number of chemicals as in the table):

| | | | Number of Chemicals Exceeding ML Values |
|---|---|---|---|
| | **No Amphipod or Benthic Effects** | | |
| EBCHEM | SS-10 | A, B | 7 |
| | **Amphipod Effects But No Benthic Effects** | | |
| EBCHEM | AB-01 | A*, B | 7 |
| | **Benthic Effects But No Amphipod Effects** | | |
| EBCHEM | SS-04 | A, B* | 5 |
| | WW-14 | A, B* | 2 |

[d] The concentration of the single chemical exceeding ML values at the four stations noted is less than twice the ML. Therefore, the station would qualify for the single chemical exception allowed by PSDDA (Keith et al. 1988).

## TABLE 9. CHEMICAL CONCENTRATIONS EXCEEDING PSDDA MAXIMUM LEVEL VALUES AT STATIONS NOT EXHIBITING ALL ADVERSE BIOLOGICAL EFFECTS TESTED

| Chemical | Station | Concentration | Qualifier | Factor by Which PSDDA ML Value Is Exceeded |
|---|---|---|---|---|
| **EHCHEM Survey (Eagle Harbor)** | | | | |
| Acenaphthene | * EH-15 | 980 ppb | | 1.56 |
| Anthracene | * EH-05 | 1,900 ppb | | 1.46 |
| | * EH-15 | 13,000 ppb | | 10.00 |
| 2,4-Dimethylphenol | * EH-05 | 59 ppb | | 1.18 |
| | * EH-15 | 72 ppb | | 1.44 |
| Fluoranthene | * EH-15 | 9,800 ppb | | 1.56 |
| Fluorene | * EH-15 | 1,800 ppb | | 2.81 |
| Naphthalene | * EH-15 | 2,400 ppb | | 1.14 |
| Phenanthrene | * EH-15 | 5,400 ppb | | 1.69 |
| Pyrene | * EH-15 | 11,000 ppb | | 1.51 |
| **EVCHEM Survey (Everett Harbor)** | | | | |
| 4-Methylphenol | ES-03 | 1,400 ppb | | 1.17 |
| | * EW-12 | 3,600 ppb | 3.00 | |
| | NG-10 | 1,800 ppb | | 1.50 |
| | NG-14 | 2,100 ppb | | 1.75 |
| Benzoic acid | ES-03 | 760 ppb | | 1.10 |
| **EBCHEM Survey (Elliott Bay)** | | | | |
| METALS | | | | |
| silver | SS-05 | 5.9 ppm | E[a], M[b] | 1.13 |
| | * SS-07 | 5.9 ppm | E | 1.13 |
| copper | * WW-19 | 1,300 ppm | | 1.61 |
| LPAH | | | | |
| acenaphthylene | * EW-14 | 1,300 ppb | X[c] | 2.03 |
| | * SS-07 | 1,200 ppb | | 1.88 |
| acenaphthene | * SS-07 | 730 ppb | E | 1.16 |
| | * WW-04 | 2,000 ppb | E | 3.17 |
| anthracene | EW-14 | 4,400 ppb | | 3.38 |
| | SS-05 | 2,600 ppb | E, M | 2.00 |
| | * SS-07 | 4,100 ppb | E | 3.15 |
| | * WW-04 | 2,000 ppb | E | 1.54 |
| naphthalene | * SS-07 | 2,700 ppb | X | 1.29 |

TABLE 9. (Continued)

| Chemical | Station | Concentration | Qualifier | Factor by Which PSDDA ML Value Is Exceeded |
|---|---|---|---|---|
| **EBCHEM Survey (Continued)** | | | | |
| fluorene | EW-14 | 1,000 ppb | E | 1.56 |
| | SS-05 | 670 ppb | L$^d$, M | 1.05 |
| | * SS-07 | 1,000 ppb | | 1.56 |
| | * WW-04 | 3,600 ppb | E | 5.63 |
| phenanthrene | EW-14 | 5,400 ppb | | 1.69 |
| | SS-05 | 3,300 ppb | E, M | 1.03 |
| | * SS-07 | 3,300 ppb | | 1.03 |
| | * WW-04 | 6,900 ppb | E | 2.16 |
| | * WW-06 | 4,200 ppb | E | 1.31 |
| 2-methylnaphthalene | * KG-06 | 1,900 ppb | | 2.84 |
| | * SS-07 | 1,400 ppb | | 2.09 |
| **HPAH** | | | | |
| benzo(a)anthracene | EW-14 | 5,100 ppb | 1.13 | 1.13 |
| fluoranthene | EW-14 | 24,000 ppb | | 3.81 |
| | * NS-07 | 12,000 ppb | E | 1.90 |
| | * SS-07 | 7,100 ppb | E | 1.13 |
| | * WW-04 | 30,000 ppb | E | 4.76 |
| pyrene | EW-14 | 16,000 ppb | | 2.19 |
| | * NS-07 | 8,300 ppb | E | 1.14 |
| | * WW-04 | 10,000 ppb | E | 1.37 |
| chrysene | EW-14 | 9,200 ppb | | 1.37 |
| total benzo-fluoranthenes (b+k) | * SS-07 | 9,900 ppb | | 1.24 |
| **Total HPAH** | EW-14 | 69,000 ppb | E | 1.35 |
| | * WW-04 | 53,000 ppb | E | 1.04 |
| **Total LPAH** | EW-14 | 13,000 ppb | E | 2.13 |
| | SS-05 | 9,400 ppb | E | 1.54 |
| | * SS-07 | 13,000 ppb | E | 2.13 |
| | * WW-04 | 15,000 ppb | E | 2.46 |
| **Total PCBs** | * KG-06 | 3,100 ppb | E | 1.24 |
| **Phenols** | | | | |
| 2,4-dimethylphenol | * SS-07 | 210 ppb | E | 4.20 |
| 4-methylphenol | * KG-09 | 1,500 ppb | E | 1.25 |
| | * WW-19 | 2,600 ppb | | 1.61 |
| **Pesticides** | | | | |
| p,p'-DDT | * KG-06 | 270 ppb | E | 3.91 |

TABLE 9. (Continued)

| Chemical | Station | Concentration | Qualifier | Factor by Which PSDDA ML Value Is Exceeded |
|---|---|---|---|---|
| **EBCHEM Survey (Continued)** | | | | |
| **Miscellaneous Organic Compounds** | | | | |
| benzyl alcohol | EW-12 | 870 ppb | E | 11.92 |
| dibenzofuran | * SS-07 | 700 ppb | E | 1.30 |
| | * WW-04 | 1,700 ppb | E | 3.15 |
| **EBCHEM Stations Excluded from Calculation of 1988 AET for One or More Biological Indicators[e]** | | | | |
| chromium | SS-10 | 1,080 ppm | | f |
| mercury | * AB-01 | 29 ppm | E | 13.8 |
| lead | * WW-14 | 9,400 ppm | | 14.3 |
| acenaphthalene | SS-10 | 740 ppb | X | 1.16 |
| acenaphthene | * AB-01 | 1,200 ppb | E | 1.90 |
| anthracene | * AB-01 | 2,700 ppb | E | 2.08 |
| | * SS-04 | 2,800 ppb | E | 2.15 |
| | SS-10 | 2,400 ppb | | 1.85 |
| fluorene | * AB-01 | 780 ppb | E | 1.22 |
| | * SS-04 | 840 ppb | E | 1.31 |
| phenanthrene | * AB-01 | 3,300 ppb | E | 1.03 |
| | SS-10 | 3,300 ppb | | 1.03 |
| fluoranthene | * AB-01 | 10,000 ppb | E | 1.59 |
| | SS-10 | 9,400 ppb | | 1.49 |
| pyrene | SS-10 | 10,000 ppb | | 1.36 |
| | * WW-14 | 7,600 ppb | | 1.03 |
| total benzofluoranthenes (b+k) | SS-10 | 9,100 ppb | | 1.14 |
| dibenzo(a,h)anthracene | * SS-04 | 1,900 ppb | E | 1.58[g] |
| total LPAH | * AB-01 | 10,000 ppb | E | 1.64 |
| | * SS-04 | 8,900 ppb | E | 1.46 |
| | SS-10 | 7,100 ppb | | 1.16 |
| p,p'-DDT | * SS-04 | 180 ppb | | 2.61 |
| dibenzofuran | * SS-04 | 560 ppb | E | 1.04 |

NOTE: Asterisk (*) indicates stations at which chemical concentrations exceeded ML values and at least one biological indicator tested (i.e., either amphipod mortality or depressions in benthic infaunal abundance) was statistically significant ($P \leq 0.05$). At other stations, data may have been available for only one biological indicator, or both biological indicators tested were not statistically significant ($P > 0.05$).

**TABLE 9. (Continued)**

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[a] E = Estimated.

[b] M = Mean of replicate analyses.

[c] X = Labelled surrogate recovery <10% (i.e., >10x recovery correction factor applied).

[d] L = Mean concentration of replicates reflects both undetected and detected values.

[e] At EBCHEM Stations AB-01, SS-04, SS-10, and WW-14, the concentration of one chemical exceeded the concentration at all other nonimpacted stations for the same biological indicator by at least a factor of three. These stations were excluded as chemical anomalies from the calculation of 1988 AET for that biological indicator (see recommended guidelines in Section 2.4 of Barrick et al. 1988; Vol. I).

[f] No ML value has been established for chromium, which is not a PSDDA chemical of concern. However, the high chromium value at Station SS-10 resulted in its exclusion from calculation of 1988 AET for both the benthic infauna and amphipod bioassay indicators (see Section 2.4 in Barrick et al. 1988; Vol. I); ML values for several chemicals were exceeded at this station.

[g] The concentration of dibenzo(a,h)anthracene at Station SS-04 exceeds the next highest concentration at an amphipod bioassay station by a factor of 3.6 and was excluded from the calculation of 1988 amphipod AET [see Barrick et al. (1988); Vol. I]. The ML value for dibenzo(a,h)anthracene was established by the benthic infauna AET rather than the lower amphipod AET.

by an order-of-magnitude at four stations (anthracene at Station EH-15 from Eagle Harbor; mercury at Station AB-01 along Alki Beach in Elliott Bay; lead at Station WW-14 in the West Waterway of the Duwamish River; and benzyl alcohol at Station EW-12 in the East Waterway of the Duwamish River). Amphipod mortalities were generally not statistically significant ($P>0.05$) at these latter stations (three of four stations). Benthic infaunal abundances were not significantly depressed ($P>0.05$) at two of the four stations (Table 8). Neither indicator was significant only at Station EW-14 from Elliott Bay.

Concentrations of chemicals that greatly exceeded PSDDA ML values at only one nonimpacted station may be nonrepresentative. However, because of the soluble nature of creosote contamination in Eagle Harbor and in light of laboratory studies conducted by EPA on these sediments, the bioassay results for Stations EH-05 and EH-15 in Eagle Harbor should be considered representative of the potential response of the amphipod bioassay to hydrocarbon contamination.

Decision guidelines for treating nonimpacted stations with anomalously high chemical concentrations (e.g., stations listed in footnote c of Table 8) are discussed in Volume I of the sediment quality values refinement reports (Barrick et al. 1988; Volume I, Section 2.4 and Appendix C). Under these guidelines, the representativeness of such stations was considered to be a technical concern for AET generation. The AET database was screened for sediment with any chemical concentration that was greater than a factor of 3 times that at the next highest nonimpacted station. From a management perspective, this guideline would generate more protective (sensitive) sediment quality values that may also be less efficient in only identifying problem sediments. As described in Barrick et al. (1988), anomalous sediments were considered nonrepresentative and were not used in AET generation unless and until additional data become available to substantiate that they are representative.

A comparison of predictive sensitivity and efficiency of PSDDA ML values for different geographic areas is presented in Figure 7. For benthic infaunal abundance, sensitivity of predictions ranged from approximately 40 to 60 percent for six of the seven geographic areas shown in Figure 7. Sensitivity for the South Seattle Waterfront was 100 percent. By contrast with sensitivity, efficiency of predictions for benthic infaunal analyses ranged between approximately 60 and 100 percent. An efficiency of 100 percent was achieved for North Harbor Island, West Waterway, and Eagle Harbor. For amphipod mortality bioassays, both sensitivity and efficiency of predictions varied widely, ranging from approximately 30 to 100 percent. A sensitivity of 100 percent was found for the South Seattle Waterfront, West Waterway, and Eagle Harbor. An efficiency of 100 percent was achieved for North Harbor Island and the Duwamish River.

## 3.3 RELIABILITY OF AET DERIVED FROM MULTIPLE BIOLOGICAL INDICATORS

AET were developed for each chemical of concern for multiple biological indicators because different kinds of biological indicators respond in different ways to the same chemical exposure. For example, an assessment of acute lethal toxicity to contaminated sediments is expected to result in different sediment quality values than an assessment of acute or chronic sublethal toxicity to the same sediments. Acute or sublethal responses by different biological species also can differ. For example, the LAET for one chemical (e.g., PCBs) may be established by the Microtox bioassay, and for another chemical (e.g., lead) by benthic infaunal analyses. The LAET is expected to be protective of a range of biological effects, although the LAET is often higher

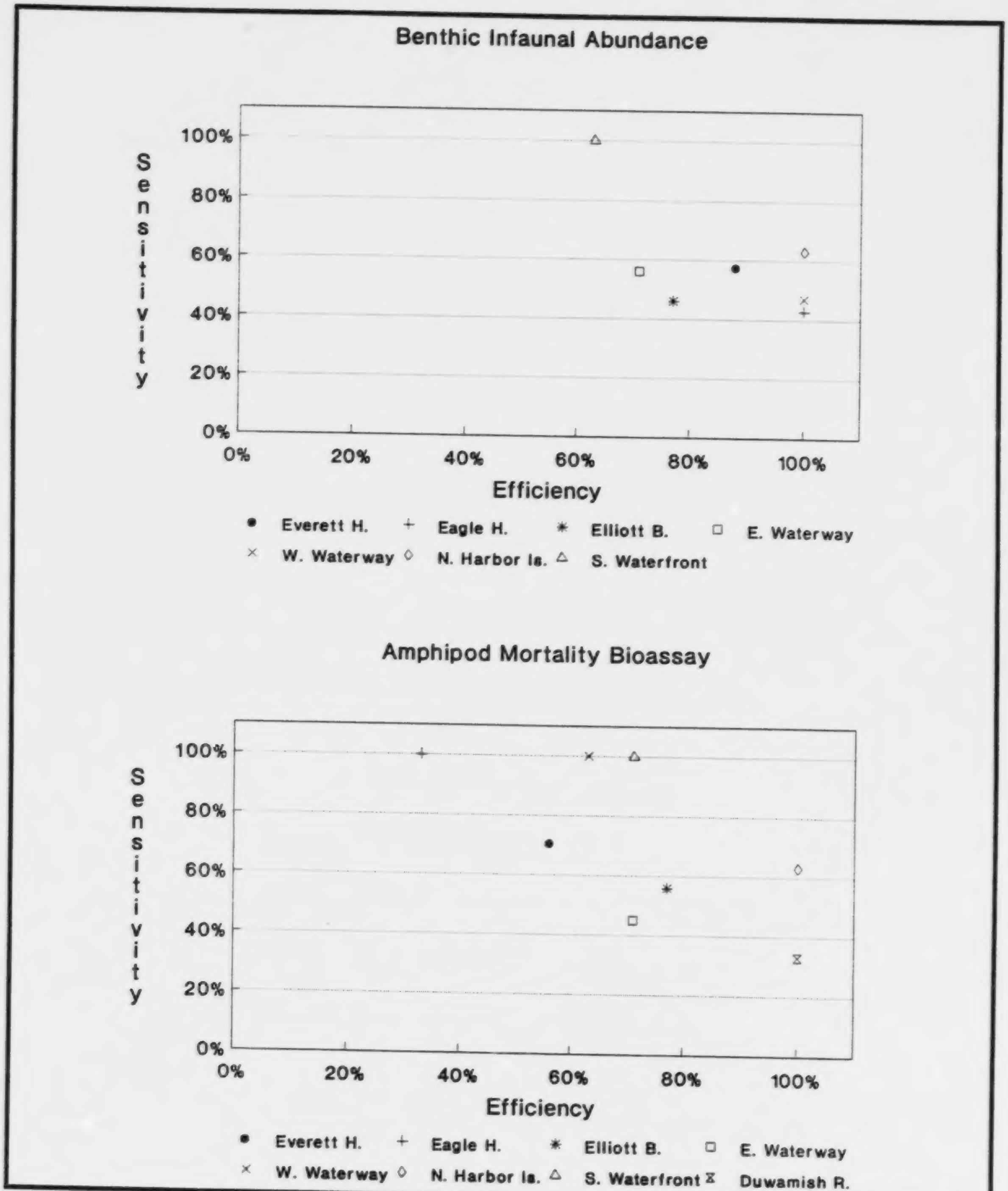

Figure 7. Comparison of the sensitivity and efficiency of PSDDA maximum level values in Eagle Harbor, Everett Harbor, and Elliott Bay, and selected geographic areas of Elliott Bay

than the PSDDA SL value. Application of 1986 Puget Sound LAET (Table 10) to the 11-survey Puget Sound database resulted in the following sensitivities:

- 89 percent based on benthic infaunal analyses (96 of 108 impacted stations)
- 85 percent based on amphipod bioassays (90 of 106 impacted stations)
- 100 percent based on Microtox (29 of 29 impacted stations) or oyster larvae bioassays (17 of 17 impacted stations).

For comparison to LAET, the highest chemical concentration (or detection limit) for nonimpacted stations from Puget Sound reference areas (HREF) was used as a modified sediment quality value (Table 10). The 28 stations used to determine these values are listed in Table B-3 (Appendix B). Detection limits were included in the calculation of HREF to give an indication of the effect of detection limits on achieving adequate sensitivity. The detection limits setting many HREF values are high relative to those that can be obtained by many methods now in use, but are typical of the detection limits available using less sensitive "screening" analyses, such as were performed for the EIGHTBAY survey. (Note: when sediment quality values are later used to compare to chemical concentrations at stations, only detected values at the stations are used to determine if the sediment quality value has been exceeded.) Application of the HREF values achieves the following sensitivities for the 11-survey database:

- 97 percent based on benthic infaunal analyses (105 of 108 impacted stations)
- 94 percent based on amphipod bioassays (100 of 106 impacted stations)
- 100 percent based on Microtox (29 impacted stations) or oyster larvae bioassays (17 impacted stations).

The approximate 10 percent increase in sensitivity for HREF relative to 1986 LAET values (based on benthic infauna and amphipod bioassay indicators) results almost exclusively from lower HREF values established for metals and PAH (Table 10).

As part of the analysis of 1986 LAET, the apparent sensitivity of each biological indicator to different chemicals based on AET was also summarized (Table 11). The 1986 LAET for HPAH, PCBs, chlorinated benzenes, and chlorinated butadienes is always established by results from the Microtox bioassay. With the exception of mercury and nickel, the LAET for metals is always established by results from benthic infaunal analyses. Several of the biological indicators jointly establish LAET for LPAH, phenols, and several other miscellaneous compounds (Table 11). Nineteen LAET are established at the same concentration by more than one biological indicator. The following numbers of 1986 LAET are uniquely established by each indicator:

- Amphipod bioassay - 3 LAET
- Benthic infaunal analyses - 9 LAET
- Oyster larvae bioassay - 1 LAET
- Microtox bioassay - 23 LAET.

## TABLE 10. HIGHEST REFERENCE AREA VALUES (HREF), 1986 LOWEST AET (LAET), AND 1986 HIGHEST AET (HAET) VALUES

| Chemical | HREF$^{a}$ | 1986 LAET$^{b}$ | 1986 HAET$^{c}$ |
|---|---|---|---|
| **Metals (mg/kg dry weight; ppm)** | | | |
| Antimony | 2.8$^{d}$ | 3.2 | 26 |
| Arsenic | 22 | 85 | 700 |
| Cadmium | 1.5 | 5.8 | 9.6 |
| Copper | 56 | 310 | 810 |
| Lead | 23 | 300 | 660 |
| Mercury | 0.12 | 0.41 | 2.1 |
| Nickel | 120$^{d}$ | 28 | 120 |
| Silver | 0.78 | 5.2 | 5.2 |
| Zinc | 102 | 260 | 1,600 |
| **Organic Compounds** (ug/kg dry weight; ppb) | | | |
| Low Molecular Weight PAH | U 600$^{e}$ | 5,200 | 6,100 |
| Naphthalene | U 100$^{e}$ | 2,100 | 2,100 |
| Acenaphthylene | U 100$^{e}$ | 560 | 640 |
| Acenaphthene | U 100$^{e}$ | 500 | 630 |
| Fluorene | U 100$^{e}$ | 540 | 640 |
| Phenanthrene | 170 | 1,500 | 5,400 |
| Anthracene | U 100$^{e}$ | 960 | 1,900 |
| 2-Methylnaphthalene | 22 | 670 | 670 |
| High Molecular Weight PAH | U 2,350$^{e}$ | 12,000 | 51,000$^{f}$ |
| Fluoranthene | U 100$^{e}$ | 1,700 | 6,300 |
| Pyrene | U 100$^{e}$ | 2,600 | 7,300$^{f}$ |
| Benz(a)anthracene | U 100$^{e}$ | 1,300 | 4,500 |
| Chrysene | U 100$^{e}$ | 1,400 | 6,700 |
| Benzofluoranthenes | U 200$^{e}$ | 3,200 | 8,000 |
| Benzo(a)pyrene | U 250$^{e}$ | 1,600 | 6,800 |
| Indeno(1,2,3,-c,d)pyrene | U 500$^{e}$ | 600 | 5,200$^{f}$ |
| Dibenzo(a,h)anthracene | U 500$^{e}$ | 230 | 1,200 |
| Benzo(g,h,i)perylene | U 500$^{e}$ | 670 | 5,400 |
| Total PCBs | U 170$^{e}$ | 130 | 2,500 |
| Chlorinated Benzenes | | | |
| 1,3-Dichlorobenzene | U 160$^{e}$ | g | g |
| 1,4-Dichlorobenzene | U 120$^{e}$ | 110 | 260 |
| 1,2-Dichlorobenzene | U 100e | 35 | 350$^{f}$ |
| 1,2,4-Trichlorobenzene | U 200$^{e}$ | 31 | 64 |
| Hexachlorobenzene | U 800$^{e}$ | 70 | 230 |
| Phthalates | | | |
| Dimethyl phthalate | U 100$^{e}$ | 71 | 160 |
| Diethyl phthalate | U 100$^{e}$ | 97 | 97 |
| Di-n-butyl phthalate | 760 | 1,400 | 5,100$^{f}$ |

**TABLE 10. (Continued)**

| | | | |
|---|---|---|---|
| Phthalates (continued) | | | |
| Butyl benzyl phthalate | U 100[e] | 63 | 470 |
| Bis(2-ethylhexyl)phthalate | 2,800 | 1,900 | 3,100[f] |
| Di-n-octyl phthalate | U 100[e] | g | g |
| Phenols | | | |
| Phenol | 560 | 420 | 1,200 |
| 2-Methylphenol | U 50[e] | 63 | 72[f] |
| 4-Methylphenol | 290 | 670 | 1,200 |
| 2,4-Dimethyl phenol | U 250[e] | 29 | 50[f] |
| Pentachlorophenol | U1,500[e] | g | g |
| Miscellaneous Extractable Compounds | | | |
| Benzyl alcohol | U 340[d] | 57 | 73 |
| Benzoic acid | 430 | 650 | 690[f] |
| Dibenzofuran | 14 | 540 | 540 |
| Hexachloroethane | U 250[e] | g | g |
| Hexachlorobutadiene | U 570[e] | 120 | 290 |
| N-Nitrosodiphenylamine | U2,500[e] | 40 | 220 |
| Volatile organics | | | |
| Trichloroethene | 15 | g | g |
| Tetrachloroethene | U 15[e] | 140 | 210[f] |
| Ethylbenzene | U 15[e] | 33 | 50[f] |
| Total xylenes | U 3[e] | 100 | 160[f] |
| Pesticides | | | |
| p,p'-DDE | U 25[e] | 9 | 15 |
| p,p'-DDD | U 25[e] | 2 | 43 |
| p,p'-DDT | U 25[e] | 3.9 | 11 |
| Aldrin | U 25[e] | g | g |
| Chlordane | U 50[e] | g | g |
| Dieldrin | U 25[e] | g | g |
| Heptachlor | U 50[e] | g | g |
| gamma-HCH (lindane) | U 50[e] | g | g |

[a] HREF = highest concentration (or detection limit) at a nonimpacted Puget Sound reference area station (i.e., a station not exhibiting adverse biological effects). See Table B-3 for a list of stations.

[b] 1986 LAET = lowest AET established in 1986 for the Microtox bioassay, oyster larvae bioassay, amphipod bioassay, or abundance of benthic infauna.

[c] 1986 HAET = highest AET established in 1986 for the Microtox bioassay, oyster larvae bioassay, amphipod bioassay, or abundance of benthic infauna.

TABLE 10. (Continued)

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[d] Antimony and nickel were not used in evaluations of ML and SL for the reasons stated in Section 2.

[e] These values represent detection limits; no detected values at the reference area stations exceeded these limits (these detection limits are high relative to those that can be obtained by many methods now in use but are typical of the detection limits available using less sensitive "screening" analyses, such as were performed for the EIGHTBAY survey)

[f] The HAET for these chemicals were established using a "greater than" value (see footnote **a** in Table 1); such values were only used for chemicals that had at least one defined AET at a lower concentration than the "greater than" value shown.

[g] No defined AET are available for these compounds (see footnote **a** in Table 1).

## TABLE 11. AET ESTABLISHING LOWEST 1986 AET (LAET) FOR EACH BIOLOGICAL INDICATOR AND CHEMICAL

| Chemical | Amphipod Bioassay | Benthic Analyses | Oyster Bioassay | Microtox Bioassay |
|---|---|---|---|---|
| **Metals** | | | | |
| Antimony | | X[a] | | |
| Arsenic | | X | | |
| Cadmium | | X | | |
| Copper | | X | | |
| Lead | | X | | |
| Mercury | | | | X |
| Nickel | | | | X |
| Silver | --[b] | X | -- | -- |
| Zinc | | X | | |
| **Organic Compounds** | | | | |
| Total LPAH | X | | X | X |
| Naphthalene | X | X | X | X |
| Acenaphthylene | X | | -- | -- |
| Acenaphthene | | X | X | X |
| Fluorene | X | | X | X |
| Phenanthrene | | | X | X |
| Anthracene | | | X | X |
| 2-Methylnaphthalene | X | X | X | X |
| Total HPAH | | -- | | X |
| Fluoranthene | | | | X |
| Pyrene | | -- | | X |
| Benzo(a)anthracene | | | | X |
| Chrysene | | | | X |
| Total benzofluoranthenes (b+k) | | | | X |
| Benzo(a)pyrene | | | X | X |
| Indeno(1,2,3-c,d)pyrene | | -- | | X |
| Dibenzo(a,h)anthracene | | | X | X |
| Benzo(g,h,i)perylene | | | | X |
| Total PCBs | | | | X |
| Chlorinated Benzenes | | | | |
| 1,3-Dichlorobenzene | -- | -- | -- | -- |
| 1,4-Dichlorobenzene | | | | X |
| 1,2-Dichlorobenzene | -- | | | X |
| 1,2,4-Trichlorobenzene | | | | X |
| Hexachlorobenzene | | | | X |

TABLE 11. (Continued)

| Chemical | Amphipod Bioassay | Benthic Analyses | Oyster Bioassay | Microtox Bioassay |
|---|---|---|---|---|
| Phthalates | | | | |
| Dimethyl phthalate | | | | X |
| Diethyl phthalate | -- | X | -- | -- |
| Di-n-butyl phthalate | -- | -- | X | X |
| Butyl benzyl phthalate | -- | | -- | X |
| Bis(2-ethylhexyl)phthalate | -- | X | X | X |
| Di-n-octyl phthalate | -- | -- | -- | -- |
| Phenols | | | | |
| Phenol | | | X | |
| 2-Methylphenol | X | -- | X | -- |
| 4-Methylphenol | -- | X | X | X |
| 2,4-Dimethylphenol | -- | X | X | X |
| Pentachlorophenol | -- | -- | -- | -- |
| Miscellaneous Extractable Compounds | | | | |
| Benzyl alcohol | | | | X |
| Benzoic acid | -- | X | X | X |
| Dibenzofuran | X | X | X | X |
| Hexachloroethane | -- | -- | -- | -- |
| Hexachlorobutadiene | | | | X |
| N-nitrosodiphenylamine | | | | X |
| Volatile Organic Compounds | | | | |
| Ethyl benzene | -- | | | X |
| Trichloroethene | -- | -- | -- | -- |
| Tetrachloroethylene | -- | X | X | X |
| Total xylenes | -- | | | X |
| Pesticides | | | | |
| p,p'-DDE | | X | -- | -- |
| p,p'-DDD | | X | -- | -- |
| p,p'-DDT | X | | -- | -- |
| Aldrin | -- | -- | -- | -- |
| Heptachlor | -- | -- | -- | -- |
| Dieldrin | -- | -- | -- | -- |
| Chlordane | -- | -- | -- | -- |
| gamma-HCH (lindane) | -- | -- | -- | -- |

TABLE 11. (Continued)

| Chemical | Amphipod Bioassay | Benthic Analyses | Oyster Bioassay | Microtox Bioassay |
|---|---|---|---|---|
| Conventional Variables | | | | |
| Oil and grease | | | | X |
| Sulfides | -- | X | X | X |
| Total organic carbon | X | X | X | X |
| Total volatile solids | | X | X | X |
| Total nitrogen | | X | X | X |

[a] X = Lowest AET value for this chemical (multiple X in a row indicate equal AET values).

[b] -- = No AET available for this biological indicator and chemical.

The trends shown in Table 11 suggest that 1986 LAET should be especially sensitive for amphipod bioassay results because the 1986 amphipod bioassay AET frequently exceeds LAET. The 85 percent sensitivity noted for the LAET at amphipod bioassay stations demonstrates, however, that LAET are not perfectly predictive of amphipod toxicity. Given the probable influence of factors other than chemical toxicity in producing amphipod mortalities (e.g., grain size effects), this reduction of sensitivity from 100 percent is not surprising.

Used in combination, AET for multiple biological indicators can also provide a preponderance of evidence for associating environmental effects and chemical contamination. Above the HAET for a range of biological indicators there is a high degree of confidence that sediments will fail biological testing regardless of the test, enabling efficient identification of problem sediments. The 1986 HAET have been used for this purpose as the basis for setting the PSDDA ML, although some chemicals for which 1986 HAET existed were not used by PSDDA.

Biological indicators that establish each 1986 HAET are summarized in Table 12. The 1986 HAET for individual and total HPAH are always established by results from benthic infauna analyses and HAET for PCBs, mercury, nickel, and antimony are established by results from amphipod bioassays. Nineteen HAET are established at the same concentration by more than one biological indicator. The following numbers of 1986 HAET are uniquely established by each indicator:

- Amphipod bioassay - 24 HAET
- Benthic infaunal analyses - 16 HAET
- Oyster larvae bioassay - none
- Microtox bioassay - none.

Application of 1986 HAET shown in Table 10 resulted in the following efficiencies for the 11-survey database:

- 81 percent based on benthic infaunal analyses (62 of 77 predicted stations were actually impacted)
- 68 percent based on amphipod bioassays (56 of 82 predicted stations were actually impacted)
- 100 percent based on Microtox or oyster larvae bioassays; however this efficiency is by constraint because all nonimpacted stations included in the calculation of HAET were also those used for predictions (data for these two biological indicators are currently available only for Commencement Bay-Carr Inlet surveys).

These efficiencies are comparable to those for ML (see Figure 6), although the additional chemicals included in HAET but not included in ML result in some lowering of the efficiency based on amphipod bioassay results. A summary comparison of both sensitivity and efficiency for HAET, LAET, and PSDDA SL and ML is presented in the following section.

## TABLE 12. AET ESTABLISHING HIGHEST 1986 AET (HAET) FOR EACH BIOLOGICAL INDICATOR AND CHEMICAL

| Chemical | Amphipod Bioassay | Benthic Analyses | Oyster Bioassay | Microtox Bioassay |
|---|---|---|---|---|
| **Metals** | | | | |
| Antimony | X | | | |
| Arsenic | | | X[a] | X |
| Cadmium | | | X | X |
| Copper | X | | | |
| Lead | X | | X | |
| Mercury | X | | | |
| Nickel | X | | | |
| Silver | --[b] | X | -- | -- |
| Zinc | | | X | X |
| **Organic Compounds** | | | | |
| Total LPAH | | X | | |
| Naphthalene | X | X | X | X |
| Acenaphthylene | | X | | |
| Acenaphthene | X | | | |
| Fluorene | | X | | |
| Phenanthrene | X | | | |
| Anthracene | X | | | |
| 2-methylnaphthalene | X | X | X | X |
| Total HPAH | | X[c] | | |
| Fluoranthene | | X | | |
| Pyrene | | X[c] | | |
| Benzo(a)anthracene | | X | | |
| Chrysene | | X | | |
| Total benzofluoranthenes (b+k) | | X | | |
| Benzo(a)pyrene | | X | | |
| Indeno(1,2,3-c,d)pyrene | | X[c] | | |
| Dibenzo(a,h)anthracene | | X | | |
| Benzo(g,h,i)perylene | | X | | |
| Total PCBs | X | | | |
| Chlorinated Benzenes | | | | |
| 1,3-Dichlorobenzene | X[c] | X[c] | X[c] | X[c] |
| 1,4-Dichlorobenzene | X | | | |
| 1,2-Dichlorobenzene | X[c] | | | |
| 1,2,4-Trichlorobenzene | | X | X | |
| Hexachlorobenzene | | X | X | |

**TABLE 12. (Continued)**

| Chemical | Amphipod Bioassay | Benthic Analyses | Oyster Bioassay | Microtox Bioassay |
|---|---|---|---|---|
| Phthalates | | | | |
| Dimethyl phthalate | X | X | X | |
| Diethyl phthalate | -- | X | -- | -- |
| Di-n-butyl phthalate | X[c] | X[c] | | |
| Butyl benzyl phthalate | X[c] | X | X[c] | |
| Bis(2-ethylhexyl)phthalate | X[c] | | | |
| Di-n-octyl phthalate | -- | X[c] | -- | -- |
| Phenols | | | | |
| Phenol | | X | | X |
| 2-Methylphenol | | X[c] | | X[c] |
| 4-Methylphenol | X | | | |
| 2,4-Dimethylphenol | X[c] | | | |
| Pentachlorophenol | X[c] | X[c] | X[c] | X[c] |
| Miscellaneous Extractable Compounds | | | | |
| Benzyl alcohol | X | X | X | |
| Benzoic acid | X[c] | | | |
| Dibenzofuran | X | X | X | X |
| Hexachloroethane | -- | -- | -- | -- |
| Hexachlorobutadiene | X | | | |
| N-nitrosodiphenylamine | X | | | |
| Volatile Organic Compounds | | | | |
| Ethyl benzene | X[c] | | | |
| Trichloroethene | -- | -- | -- | -- |
| Tetrachloroethylene | X[c] | | | |
| Total xylenes | X[c] | | | |
| Pesticides | | | | |
| p,p'-DDE | X | | -- | -- |
| p,p'-DDD | X | X | -- | -- |
| p,p'-DDT | | X | -- | -- |
| Aldrin | -- | -- | -- | -- |
| Heptachlor | -- | -- | -- | -- |
| Dieldrin | -- | -- | -- | -- |
| Chlordane | -- | -- | -- | -- |
| gamma-HCH (lindane) | -- | -- | -- | -- |

**TABLE 12. (Continued)**

| Chemical | Amphipod Bioassay | Benthic Analyses | Oyster Bioassay | Microtox Bioassay |
|---|---|---|---|---|
| Conventional Variables | | | | |
| Oil and grease | | X | | X |
| Sulfides | X | | | |
| Total organic carbon | X | X | X | X |
| Total volatile solids | X | | | |
| Total nitrogen | X | | | |

[a] X = Highest AET value for this chemical (multiple X in a row indicate equal AET values).

[b] -- = No defined AET available for this biological indicator and chemical.

[c] The AET for this indicator is a preliminary "greater than" value (see footnote a in Table 1), which, although not a defined AET, is the highest AET value.

## 3.4 OPTIMIZATION OF SENSITIVITY AND EFFICIENCY OF SEDIMENT QUALITY VALUES

Of the 201 benthic infauna stations and 287 amphipod bioassay stations evaluated, approximately 93 percent (188 stations and 264 stations, respectively) are in accordance with the prediction of the PSDDA ML and SL values (i.e., they do not exhibit adverse effects at chemical concentrations less than SL values, and do exhibit adverse effects at chemical concentrations above ML values). Moreover, one or the other of these biological indicators is in accordance with predictions of PSDDA ML and SL values at 17 of the 22 (77 percent) remaining stations for which data for both benthic infauna and amphipod bioassays are available (Tables 6 and 8). These results indicate that the PSDDA values generally are reliable, but are not perfectly sensitive or efficient. To assess the importance of 100 percent sensitivity and efficiency of PSDDA sediment quality values, the PSEP/PSDDA agencies requested determination of the following three sets of values:

1. The combination of chemical concentrations below the 1986 Puget Sound AET values (Table 1) that produces 100 percent "within-database" sensitivity (i.e., all biologically impacted stations in the existing database used to derive AET are correctly identified)

2. The combination of chemical concentrations below the 1986 Puget Sound AET values that produces 100 percent predictive sensitivity for the Eagle Harbor and PSEP Elliott Bay and Everett Harbor data sets (i.e., all biologically impacted stations in the independent data sets are correctly identified)

3. The combination of chemical concentrations above the 1986 Puget Sound AET values that produces 100 percent predictive efficiency for the Eagle Harbor and PSEP Elliott Bay and Everett Harbor data sets (e.g., only biologically impacted stations in the independent data sets are identified).

A wide variety of combinations of modified AET could satisfy these requirements. Adjustments to a subset of AET that may account for most of the sensitivity or efficiency of sediment quality values is a possible approach. Such a subset of AET is evaluated in Volume I of this sediment quality values refinement report (Figure 1; see Section 3.3.4 in Barrick et al. 1988). The approaches taken in this volume of the report to determine 100 percent sensitivity (requirements 1 and 2 above) and 100 percent efficiency (requirement 3 above) are summarized in the following sections.

### 3.4.1 Sensitivity

Two alternative approaches were used to optimize the sensitivity of sediment quality values. In the first approach, stations were identified at which no chemical concentration exceeded 1986 LAET but adverse biological effects were observed. Chemicals detected at the highest concentration relative to the 1986 LAET were identified for each of these impacted stations. If LAET were modified downward to account for these chemical concentrations, 100 percent sensitivity could be nominally achieved. This approach was preferred over other arbitrary adjustments of AET (e.g., applying constant factors to all AET) because the following iterative process could be used to minimize the number of modifications to achieve 100 percent sensitivity and reduce losses in efficiency:

Step 1. Among all stations not correctly predicted by 1986 LAET, identify the station with the lowest maximum concentration of any chemical relative to LAET.

Step 2. Modify the LAET to less than this chemical concentration.

Step 3. Identify any stations that are still not correctly predicted with respect to this modified LAET. Repeat Steps 1-3 to account for all remaining stations that were not correctly predicted.

Although these modifications produce 100 percent sensitivity for the Puget Sound database, it is important to note that these modifications are arbitrary deviations from the AET concept and cannot be given a similar interpretation relative to predicted chemical-biological relationships. The following modifications to LAET produce 100 percent sensitivity for the surveys used to calculate the 1986 Puget Sound AET:

- Modify di-n-butyl phthalate LAET from 1,400 to 410 ppb
- Modify mercury LAET from 0.41 to 0.13 ppm
- Modify zinc LAET from 260 to 36 ppm.

These modifications also produce 100 percent sensitivity for the new Elliott Bay (EBCHEM) and Everett Harbor (EVCHEM) surveys. To produce 100 percent sensitivity for the Eagle Harbor survey, modification of the diethyl phthalate LAET from 97 to 53 ppb is also necessary to account for impacted Station EH-03. A summary of the efficiency and sensitivity of the predictions using these modified LAET is presented in Table 13. The efficiency of these values is comparable but somewhat less than that obtained using PSDDA SL values (e.g., 55 vs. 59 percent efficient for all benthic infaunal analyses and 38 vs. 40 percent for all amphipod bioassays). *Such modifications of chemical LAET are not necessarily recommended. because most of the stations that were incorrectly predicted by 1986 LAET are stations at which grain size or other physical factors may account for the observed biological response.* Modification of LAET to account for such stations will produce 100 percent sensitivity for the database, but will also reduce efficiency. Other procedures not tested may produce smaller losses in efficiency.

### 3.4.2 Efficiency

Recalculation of AET based on the entire 11-survey database is the most direct means of determining the combination of chemical concentrations above the 1986 Puget Sound AET values that produces 100 percent predictive efficiency for the Eagle Harbor and PSEP Elliott Bay and Everett Harbor data sets. Reliability analyses for these AET that were recalculated in 1988 are summarized in Volume I of the sediment quality values report (Barrick et al. 1988). The 1988 HAET based on these 1988 AET (i.e., 1988 HAET) are, for the stations included in the calculation of AET, 100 percent efficient. After adding to the reliability analysis the nonimpacted stations that were identified as chemical anomalies, the efficiency of 1988 HAET decreases to 91 percent for benthic

## TABLE 13. COMPARISON OF THE SENSITIVITY AND EFFICIENCY OF MODIFIED LAET VALUES[a]

| Biological Indicator | Number of Stations Evaluated | Impacted | Predicted | Correctly Predicted | Sensitivity | Efficiency |
|---|---|---|---|---|---|---|
| Benthic Infaunal Abundance | 92[b]<br>201[c] | 37<br>108 | 86<br>195 | 37<br>108 | 100 %<br>100 % | 43 %<br>55 % |
| Amphipod Bioassay | 148[b]<br>287[c] | 53<br>106 | 137<br>276 | 53<br>106 | 100 %<br>100 % | 39 %<br>38 % |
| Microtox Bioassay | 50[b] | 29 | 47 | 29 | 100 % | 62 % |
| Oyster Larvae Bioassay | 56[b] | 17 | 53 | 17 | 100 % | 32 % |

[a] Modified LAET = Lowest Apparent Effects Threshold for a range of biological indicators (benthic infaunal abundance, amphipod mortality bioassay, Microtox bioassay, and oyster larvae abnormality bioassay) modified for specific chemicals as described in text.

[b] Based on benthic infauna or amphipod bioassay stations in the original surveys used to establish Puget Sound AET (i.e., excluding new Eagle Harbor, Elliott Bay, and Everett Harbor surveys).

[c] Based on benthic infauna or amphipod bioassay stations in all surveys in the sediment quality values database (i.e., including new Eagle Harbor, Elliott Bay, and Everett Harbor surveys).

infauna stations (four nonimpacted benthic stations were excluded from 1988 AET calculations as chemical anomalies) and to 85 percent for amphipod bioassays (eight nonimpacted amphipod stations were excluded from 1988 AET calculations as chemical anomalies). There is no change in the 100 percent efficiency for oyster larvae and Microtox bioassays because no stations were excluded from the calculation of these AET.

Recalculation of 1986 HAET as 1988 HAET also minimizes (but does not prevent) loss of sensitivity. A summary comparison of sensitivity and efficiency for the 1988 HAET and other sediment quality values is provided in Table 14 and Figure 8. The 1988 HAET are as sensitive as PSDDA ML values in predicting depressions in benthic infaunal abundances or amphipod mortality, and they are more efficient. The 1988 HAET were 7 to 12 percent more sensitive than PSDDA ML values in predicting adverse responses for Microtox and oyster larvae bioassays. Such results are attributed to the contribution to sensitivity by additional chemicals not included as PSDDA chemicals of concern. When only PSDDA chemicals of concern for which there are ML values are considered, the 1988 HAET are still 100 percent efficient but the sensitivity of 1988 HAET decreases to 32 percent for benthic infauna impacts (compared with 42 percent for ML values), and 37 percent for amphipod bioassay impacts (compared with 43 percent for ML values). The sensitivity and efficiency of 1988 HAET and ML values is identical in predicting adverse impacts for Microtox and oyster larvae bioassays.

## TABLE 14. SUMMARY OF RELIABILITY FOR DIFFERENT SEDIMENT QUALITY VALUES[a]

| Biological Indicator | Sediment Quality Value[a] | Impacted | Predicted | Correctly Predicted | Sensitivity | Efficiency |
|---|---|---|---|---|---|---|
| Benthic Infaunal Abundance (201 stations) | HREF | 108 | 177 | 105 | 97 % | 59 % |
| | SL | 108 | 175 | 103 | 95 %[b] | 59 %[b] |
| | 1986 LAET | 108 | 144 | 96 | 89 % | 67 % |
| | 1986 HAET | 108 | 77 | 62 | 57 % | 81 % |
| | ML | 108 | 53 | 45 | 42 %[b] | 85 %[b] |
| | 1988 HAET | 108 | 43 | 43 | 40 % | 100 %[c] |
| | 1986 Benthic AET | 108 | 100 | 82 | 76 % | 82 % |
| Amphipod Bioassay (287 stations) | HREF | 106 | 247 | 100 | 94 % | 41 % |
| | SL | 106 | 240 | 97 | 92 %[b] | 40 %[b] |
| | 1986 LAET | 106 | 202 | 90 | 85 % | 45 % |
| | 1986 HAET | 106 | 82 | 56 | 53 % | 68 % |
| | ML | 106 | 60 | 46 | 43 %[b] | 77 %[b] |
| | 1988 HAET | 106 | 47 | 47 | 44 % | 100 %[c] |
| | 1986 Amphipod AET | 106 | 86 | 59 | 56 % | 69 % |
| Microtox Bioassay (50 stations) | HREF | 29 | 46 | 29 | 100 % | 63 % |
| | SL | 29 | 50 | 29 | 1 %[b] | 58 %[b] |
| | 1986 LAET | 29 | 31 | 27 | 93 % | 87 % |
| | 1986 HAET | 29 | 19 | 19 | 62 % | 100 %[c] |
| | ML | 29 | 7 | 7 | 24 %[b] | 100 %[c] |
| | 1988 HAET | 29 | 9 | 9 | 31 % | 100 %[c] |
| | 1986 Microtox AET | 29 | 27 | 27 | 93 % | 100 %[c] |
| Oyster Larvae Bioassay (56 stations) | HREF | 17 | 52 | 17 | 100 % | 33 % |
| | SL | 17 | 55 | 17 | 100 %[b] | 31 %[b] |
| | 1986 LAET | 17 | 36 | 16 | 94 % | 44 % |
| | 1986 HAET | 17 | 13 | 13 | 76 % | 100 %[c] |
| | ML | 17 | 7 | 7 | 41 %[b] | 100 %[c] |
| | 1988 HAET | 17 | 9 | 9 | 53 % | 100 %[c] |
| | 1986 Oyster AET | 17 | 15 | 15 | 88 % | 100 %[c] |

[a] Antimony and nickel were not considered in these evaluations (see footnote b). Values for SL, 1986 LAET, 1986 HAET, and ML were calculated using data fr eight surveys and tested with data from 11 surveys. HREF from Table 10 were also tested with field data from 11 surveys. 1988 HAET values were calculated and tested using data from all 11 surveys (i.e., including Eagle Harbor, Elliott Bay, and Everett Harbor surveys). See footnote c for results including nickel and antimony

TABLE 14. (Continued)

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[b] The sensitivity of SL and ML values generally increase and their efficiency generally decrease after consideration of nickel and antimony results (excluded for reasons discussed in Section 2):

| | Sediment Quality Value | Sensitivity | Efficiency |
|---|---|---|---|
| Benthic Infauna Abundance | SL | 97% | 56% |
| | ML | 55% | 82% |
| Amphipod Mortality Bioassay | SL | 93% | 38% |
| | ML | 55% | 82% |
| Microtox Bioassay | SL | no change | no change |
| | ML | no change | no change |
| Oyster Larvae Bioassay | SL | no change | no change |
| | ML | no change | no change |

[c] Efficiency is 100 percent by constraint; all nonimpacted stations used in the reliability check were also used to calculate these two sets of sediment quality values.

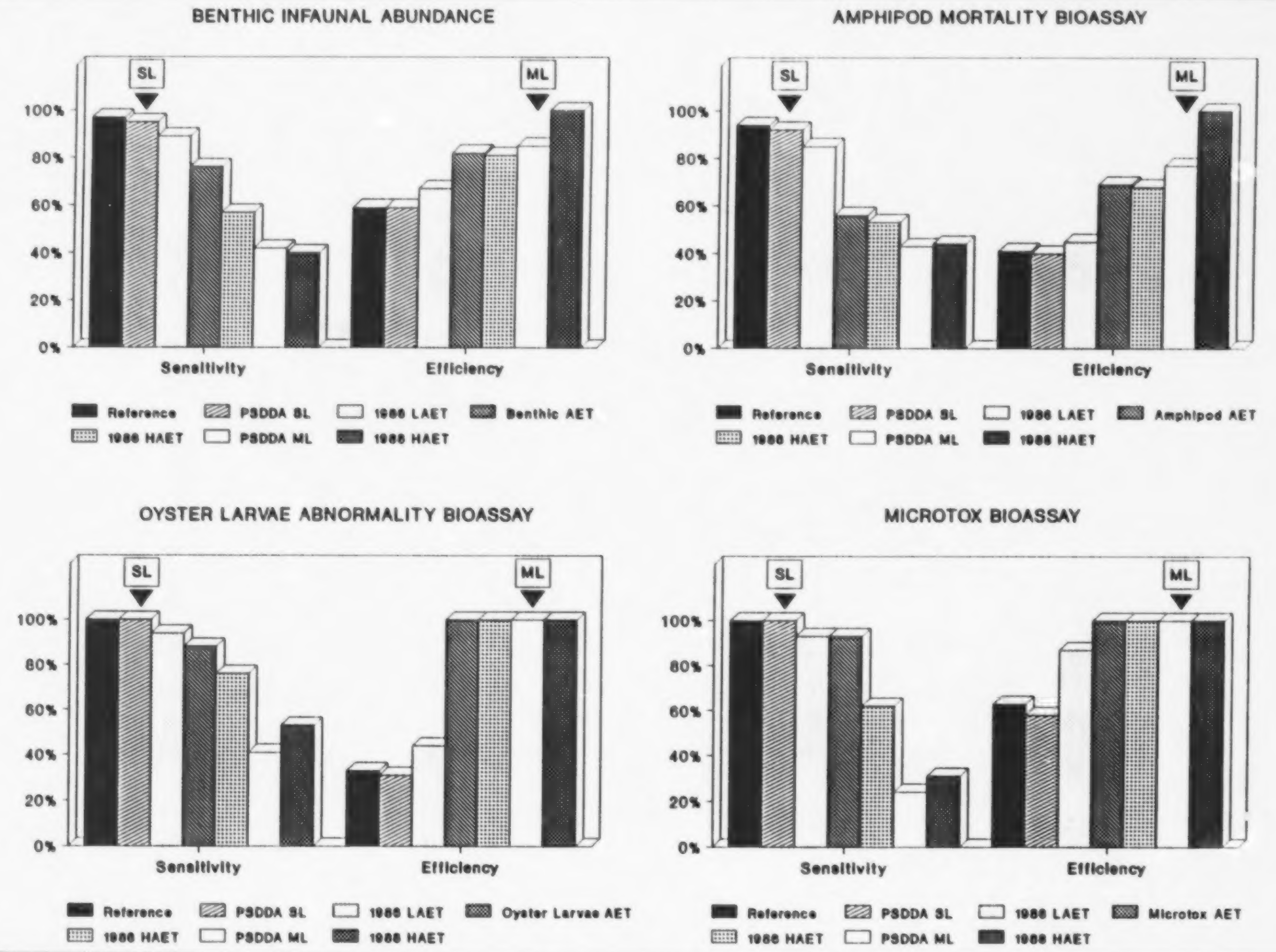

Figure 8. Summary of sensitivity and efficiency of PSDDA maximum and screening level values

# 4. SUMMARY

Evaluations conducted for this report indicate that current PSDDA SL and ML values generally are reliable in predicting adverse biological effects. Of the 201 benthic infauna stations and 287 amphipod bioassay stations evaluated, approximately 93 percent (188 benthic stations and 264 amphipod stations) are in accordance with the prediction of the PSDDA ML and SL values (i.e., they do not exhibit adverse effects at chemical concentrations less than SL values and do exhibit adverse effects at chemical concentrations above ML values). One or the other of these biological indicators is still in accordance with predictions of PSDDA ML and SL values at 17 of the 22 remaining stations (77 percent) for which data for both benthic infauna and amphipod bioassays are available.

PSDDA SL values, used as guidelines for identifying the need for biological testing of dredged material, predict from 92 to 100 percent of the stations exhibiting adverse biological effects in the available 11-survey database for Puget Sound (Figure 8). Physical characteristics (e.g., grain size, habitat exposure), high detection limits, and/or unanalyzed chemicals are likely factors accounting for the nine amphipod and five benthic infauna stations that were incorrectly predicted as not having adverse effects by PSDDA SL values (Table 14). Of these factors, grain size characteristics are considered most important. Sediments from five of the nine amphipod bioassay stations that were mispredicted were highly fine-grained (i.e., >75-90 percent), a naturally unfavorable habitat for the test organisms. Sediments from four of the five benthic infauna stations that were mispredicted were highly coarse-grained (i.e., 77-95 percent) and in some cases were collected in areas of relatively high-wave intensity compared to reference conditions. Both conditions are expected to result in reduced abundances of organisms that may not have been adequately controlled for by comparisons to reference area samples. Only one adverse biological impact was exhibited at the four stations mispredicted by SL values and at which two biological indicators were tested. Overall, there is no evidence suggesting that PSDDA SL values should be modified downward to further enhance their sensitivity. The focus of the SL evaluation was on sensitivity in identifying all impacts; however, the current SL values are 31 to 59 percent efficient in identifying only impacted stations (i.e., 41 to 69 percent of all stations predicted as potential problems by PSDDA SL values did not exhibit adverse biological effects). Sediment quality values modified to enhance sensitivity were comparable or somewhat lower in efficiency (i.e., HREF results in Table 14 and Figure 8; modified LAET results in Table 13).

The apparent sensitivity of each biological indicator to different chemicals based on AET was also evaluated. The LAET for the range of biological indicators is established by the Microtox bioassay for two metals (mercury and nickel), 20 of 53 organic chemicals, and one of five conventional variables (i.e., oil and grease). The benthic infauna indicator establishes the LAET for the other seven metals and for three organic compounds. The amphipod bioassay establishes two LAET and the oyster larvae bioassay establishes one LAET for organic chemicals. Seventeen LAET for organic chemicals and LAET for four conventional variables (sulfides, total organic carbon, total volatile solids, and total nitrogen) are established at the same concentration by more than one biological indicator (including amphipod mortality, oyster larvae abnormality, Microtox bioluminescence, or depressions in benthic infaunal abundance).

The 1986 HAET for the range of biological indicators is established by the amphipod bioassay for four metals (antimony, copper, mercury, and nickel), 17 of 53 organic compounds including PCBs, and three of five conventional variables. The benthic infauna indicator establishes the HAET for one metal (silver), 16 of 53 organic compounds including all individual and total HPAH, and one conventional variable (oil and grease). Nineteen HAET are established at the same concentration by more than one biological indicator (including oyster larvae and Microtox bioassays, although these indicators do not uniquely establish any HAET).

PSDDA ML values are used as guidelines for identifying contaminated sediments that are unsuitable for disposal at unconfined, open-water sites based on chemical data alone. From 77 to 100 percent of the stations predicted by ML values to have adverse biological effects actually exhibited the effects predicted in the available 11-survey database for Puget Sound (Figure 8; Table 14). The focus of the ML evaluation was on efficiency in identifying only impacted stations. This enhanced efficiency in detecting only problem sediments relative to PSDDA SL values is paralleled by a decrease in sensitivity (Figure 8). The current ML values are 24 to 43 percent sensitive in identifying all impacted stations in the database. Stations that did not exhibit all adverse effects that were predicted by ML values included 2 Eagle Harbor, 4 Everett Harbor, and 14 Elliott Bay stations. However, within this group of 20 stations, adverse impacts were observed for at least one biological indicator at 13 of the 18 stations at which both amphipod bioassays and benthic infauna analyses were conducted.

Chemical concentrations at 40 percent (8 of 20 stations) of these stations were within a factor of 2 of the PSDDA ML values, suggesting that enhancements in efficiency of ML values are possible with only minor revisions. Concentrations of single chemicals (i.e., anthracene or lead) exceeded ML values by more than a factor of 10 at one Eagle Harbor station and one Elliott Bay station at which the amphipod bioassay was not significant (although significant benthic impacts were observed). The concentration of mercury exceeded ML values by more than a factor of 10 at one Elliott Bay station at which the benthic infauna indicator was not significant (although significant amphipod mortality was observed).

Chemical concentrations generally exceeded ML values by less than a factor of two at the one Everett Harbor and three Elliott Bay stations at which neither biological indicator exhibited a significant response. However, the concentration of benzyl alcohol exceeded the ML value by more than a factor of 10 at one of the stations. These latter four stations represent less than 2 percent of the Puget Sound database.

1988 HAET are 100 percent efficient in predicting adverse effects for the 201 benthic infauna stations, 287 amphipod bioassay stations, 56 Microtox bioassay stations, and 50 oyster larvae bioassay stations included in the AET database (Table 14 and Figure 8). After including in the reliability analysis the nonimpacted stations that were identified as chemical anomalies (Barrick et al. 1988; Volume I), the efficiency of 1988 HAET is:

- 91 percent for benthic infauna stations (four nonimpacted benthic stations were excluded from 1988 AET calculations as chemical anomalies)
- 85 percent for amphipod bioassays (eight nonimpacted amphipod stations were excluded from 1988 AET calculations as chemical anomalies)

- 100 percent efficient for oyster larvae and Microtox bioassays (no stations were excluded).

Decision rules concerning the treatment of anomalous biological or chemical results (particularly single nonimpacted stations at which single chemical concentrations greatly exceed sediment quality values) are discussed in Volume I of this sediment quality values refinement report (Barrick et al. 1988; see Section 2.4 and Appendix C of Volume I). Revision of ML values to incorporate these anomalous stations is recommended on a case-by-case basis because such stations may reflect strictly localized, nonrepresentative conditions.

The 1988 HAET are as sensitive as PSDDA ML values in predicting depressions in benthic infaunal abundances or amphipod mortality. The 1988 HAET were 7 to 12 percent more sensitive than PSDDA ML values in predicting adverse responses for Microtox and oyster larvae bioassays. Such results are attributed to the contribution to sensitivity by additional chemicals not included as PSDDA chemicals of concern. When only PSDDA chemicals of concern for which there are ML values are considered, the 1988 HAET are still 100 percent efficient, but the sensitivity of 1988 HAET decreases to 32 percent for benthic infauna impacts (compared with 42 percent for ML values), and to 37 percent for amphipod bioassay impacts (compared with 43 percent for ML values). The sensitivity and efficiency of 1988 HAET and ML values are identical in predicting adverse impacts for Microtox and oyster larvae bioassays.

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# 6. GLOSSARY

| | |
|---|---|
| **Adverse Biological Effect** | Any change in a biological system that results in injury or damage to an organism, population, or community (e.g., failure to develop properly, death, reduced population abundance). |
| **Anomalous** | Unusual observation or localized phenomena.<br>(1) Anomalous "no effect" - An observation of "no adverse biological effect" at a station when one was predicted by comparison of chemical data with sediment quality values. For example, **biological anomalies** can result from large variance in field or laboratory measurements leading to insufficient power to detect adverse effects. A similar apparent **chemical anomaly** could also result from predictions made by sediment quality values generated for one kind of sediment matrix to another matrix that reduces the bioavailability of contaminants.<br>(2) Anomalous "Effect" - An observation of "significant biological effects" at a station where AET were not exceeded. This kind of **biological anomaly** could result from a Type I error in the statistical test for biological effects. Apparent **chemical anomalies** could also result from interactive effects of chemicals or effects of chemicals that were not analyzed. |
| **Amphipods** | Small shrimp-like crustaceans (for example, sand fleas). Many live on the bottom, feed on algae and detritus, and serve as food for many marine species. Amphipods are used in laboratory bioassays to test the toxicity of sediments. |
| **Amphipod Mortality** | A measurement of amphipod death expressed as the percentage of individuals that die within 10 days upon exposure to test sediments in the laboratory. The standard protocol involves 5 replicate test chambers containing 20 amphipods each. |
| **Apparent Effects Threshold** | The sediment concentration of a contaminant above which statistically significant ($P \leq 0.05$) adverse biological effects (relative to appropriate reference conditions) would always be expected. An AET is calculated for each chemical and biological indicator. |

|  |  |  |
|---|---|---|
| **Apparent Effects Threshold (cont.)** | **Defined AET** | An AET determined for a given chemical and given biological effect from a data set with at least one impacted station that exhibited a chemical concentration higher than the AET. |
|  | **Preliminary AET** | An AET equal to the highest chemical concentration found in a particular data set (i.e., no impacted stations with a chemical concentration higher than the AET). |
|  | **Highest AET** | The highest AET value (for a given chemical) among a set of AET for various biological indicators. |
|  | **Lowest AET** | The lowest AET value (for a given chemical) among a set of AET for various biological indicators. |
| **Benthic Infauna** |  | Macroinvertebrate organisms that live in or on the bottom of a body of water. |
| **Benthic Infauna Abundance** |  | The population density of benthic infauna typically expressed as the number of organisms per unit area of bottom (e.g., number per $m^2$), as estimated from field sampling. |
| **Bioassay** |  | A laboratory test used to evaluate the toxicity of a material (commonly sediments or wastewater) by measuring behavioral, physiological, or lethal responses of organisms. |
| **Bulk Sediment Analysis** |  | Chemical analyses performed on an entire sediment sample, without separating water from the solid material in a sample. |
| **Cause-Effect Relationship** |  | The quantitative interdependence of a biological effect variable and an environmental variable such as the concentration of a certain chemical, organic carbon, or sediment grain size. Cause-effect relationships cannot be proven using field-based approaches such as AET. |

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| **Chemical Interactive Effects** | Combined action of two or more chemicals to produce additive, synergistic, or antagonistic effects on an organism, a population, or a biological community. An additive effect results when the combined effects can be accurately predicted by the sum of the individual effects of the single chemicals. A synergistic effect results when the combined effects are greater than the sum of the individual chemical effects. An antagonistic effect results when the combined effects are less than the sum of the individual chemical effects. |
| **Contaminant** | A chemical or biological substance in a form or in a quantity that can harm aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment. |
| **Contaminated Sediment** | **Technical Definition:** A sediment that contains measurable levels of contaminants.<br>**Management Definition:** A sediment that contains sufficient quantities of contaminants to result in adverse environmental effects and thus require restrictions for dredging of dredged material, or consideration of remedial action. |
| **Conventional Pollutants** | Sediment variables and characteristics that have been routinely measured in assessing sediment quality. These include sulfides, total organic carbon, total organic nitrogen, total volatile solids, and grain size distribution (e.g., percent coarse and fine-grained material). |
| **Detection Limit** | The lowest concentration at which the presence of a particular chemical can be reliably established by a specified analytical method. Detection limits used in this report may in some cases be lower than strictly defined method detection limits (i.e., the concentration of a chemical above which there is 99 percent statistical confidence that the detected signal exceeds background noise levels). |
| **Dredged Material** | Sediments excavated from the bottom of a waterway or water body. |
| **Efficiency** | A measure of reliability for any sediment quality value. The proportion of all stations predicted to have adverse biological effects that are actually impacted. |

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| **Empirical** | Depending on or based on observations in the laboratory or the field. Also, subject to verification by observation or experiment. |
| **Equilibrium Partitioning Approach** | A theory of the distribution of chemicals in various phases (e.g., dissolved, particulate, gaseous) based on thermodynamic principles. The equilibrium partitioning approach has been used to predict the concentrations of chemicals in bulk sediments from corresponding concentrations in interstitial (pore) water, or conversely, to predict the concentrations of chemicals in interstitial water from corresponding concentrations in bulk sediment. |
| **Highest Reference Area Value** | The highest concentration (or detection limit) at a nonimpacted Puget Sound reference area station (i.e., a station not exhibiting adverse biological effects; see Table B-3). |
| **Hydrocarbon** | An organic compound composed of carbon and hydrogen. Petroleum and its derived compounds consist primarily of hydrocarbons. |
| **Impacted** | Changed from a natural state as a result of human activities. Typically, the term "impacted" is applied to describe the status of biological systems adversely affected by human activities. |
| **Intertidal Area** | The area between high and low tide levels. The alternate wetting and drying of this area makes it a transition between land and water organisms and creates special environmental conditions. |
| **Maximum Level** | A sediment quality value generally based on the highest AET for a range of biological indicators and used in PSDDA to evaluate when biological testing may be unnecessary to determine that a contaminated sediment is unsuitable for unconfined, open-water disposal. The maximum level defines the concentration of a chemical in dredged material above which there is reason to believe that unacceptable adverse impacts would result from unconfined, open water disposal. |
| **Metals** | Naturally occurring elements. Certain metals, such as mercury, lead, nickel, zinc, and cadmium can be or environmental concern when they are released to the environment in unnatural amounts by man's activities. |

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| **Microtox** | A laboratory test using luminescent bacteria and measuring light production, used to assess toxicity of saline or organic solvent extracts of sediments. |
| **Noncontradictory** | Consistent with available evidence (i.e., for AET, correct prediction of all nonimpacted stations in the data set used to generate AET is part of the noncontradictory assumption in the AET approach). |
| **Nonimpacted** | Not affected adversely by human activities. |
| **Organic Carbon** | Carbon in a form related to or derived from living things (excluding calcium carbonate). |
| **Oyster Larvae Abnormality** | A measurement of developmental defects in oyster expressed as the percentage of individuals that fail to develop properly within 48 hours upon exposure to test sediments in the laboratory. The standard protocol involves 5 replicate test chambers, each containing embryos at a density of 20-40 per milliliter. |
| **Pesticide** | A general term used to describe any substance, usually chemical, used to destroy or control organisms (pests). Pesticides include herbicides, insecticides, algicide, and fungicides. Many of these substances are manufactured and are not naturally found in the environment. Others are natural toxins that are extracted from plants and animals. |
| **Polycheate** | A marine worm of the Phylum Annelida, Class Polychaeta. |
| **Polychlorinated Biphenyls** | A group of manmade organic chemicals, including 209 different but closely related compounds (congeners) made up of carbon, hydrogen and chlorine. If released to the environment, they persist for long periods of time and can concentrate in food chains. The manufacture and use of PCBs are regulated by EPA under the Toxic Substances Control Act. |
| **Power Analysis** | A mathematical technique to determine the capacity of a statistical test to detect true differences between treatments (e.g., between amphipod mortality measured for a test sediment vs. that of a reference-area sediment). Statistical power is expressed as the probability of detecting a true difference of a specified magnitude. |

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| **Priority Pollutants** | Substances listed by EPA under the Clean Water Act as toxic and having priority for regulatory controls. The list includes toxic metals, inorganic contaminants such as cyanide and arsenic, and a broad range of both natural and artificial organic compounds. The list of priority pollutants includes some substances that are not of concern in Puget Sound, and also does not include all known harmful compounds. |
| **Puget Sound Water Quality Authority** | An agency created by the Washington State legislature in 1985 and tasked with developing a management plan to protect and enhance the water quality of Puget Sound. The Authority adopted its first plan in January 1987. |
| **Reliability** | A general quality resulting from a combination of both high sensitivity and high efficiency of sediment quality values. |
| **Screening Level** | A sediment quality value based partly on AET modified with a safety factor and used in PSDDA to evaluate when biological testing should be conducted to determine the suitability of the sediment for unconfined, open-water disposal. The screening level defines the concentration of a chemical in dredged material below which there is no reason to believe unacceptable adverse impacts would result from unconfined, open water disposal. |
| **Sediment** | Material suspended in or settling to the bottom of a liquid, such as the sand and mud that make up much of the shorelines and bottom of Puget Sound. Sediment in Puget Sound comes from natural sources (e.g., erosion of soils and weathering of rock) or anthropogenic sources (e.g., forest or agricultural practices or construction activities). Certain contaminants tend to collect on and adhere to sediment particles. The sediment of some areas around Puget Sound contain elevated levels of contaminants relative to reference areas that are located away from major contaminant sources. |
| **Sediment Quality Value** | A "benchmark" number for an environmentally acceptable concentration of a given chemical in sediments. A chemical concentration that is expected to be below the level that would consistently lead to adverse biological effects for a wide variety of species, habitats, and sediment types. |

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| **SEDQUAL** | Sediment quality data base and menu-driven program developed for Puget Sound Estuary Program |
| **Sensitivity** | A measure of reliability for any sediment quality value. The proportion of all stations exhibiting adverse biological effects that are correctly predicted by a sediment quality value. |
| **Statistically Significant** | A quantitative determination of the statistical degree to which multiple measurements of the same variable can be shown to be different, given the variability of the measurements. |
| **Subtidal** | Refers to the marine environment below low tide. |
| **Synoptic** | (or **Matched Data**) Data for different variables that are collected during a single sampling event at a single station (e.g., chemical data on sediments at a station that were also evaluated for benthic infauna abundances and sediment toxicity to amphipods). |
| **Toxic Substances and Toxicants** | Chemical substances that are poisonous, carcinogenic, or otherwise harmful to life if found in sufficient concentration. |
| **Volatile Solids** | The material in a sediment sample that vaporizes or evaporates at a given high temperature (550° C). |

# 7. ABBREVIATIONS

| | |
|---|---|
| AET | Apparent Effects Threshold |
| Authority | Puget Sound Water Quality Authority |
| Corps | U.S. Army Corps of Engineers |
| DNR | Washington Department of Natural Resources |
| Ecology | Washington Department of Ecology |
| EPA | U.S. Environmental Protection Agency |
| HAET | Highest AET |
| HREF | Highest REFerence area value (see Section 3.3) |
| LAET | Lowest AET |
| ML | Maximum level (defined in the PSDDA program) |
| PAH | Polycyclic aromatic hydrocarbons |
| PCB | Polychlorinated biphenyls |
| PSDDA | Puget Sound Dredged Disposal Analysis |
| PSEP | Puget Sound Estuary Program |
| SEDQUAL | SEDiment QUALity database |
| SL | Screening level (defined in the PSDDA program) |

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## CONCEPT OF THE AET APPROACH

An AET is defined as the sediment concentration of a given chemical above which statistically significant ($P \leq 0.05$) biological effects (e.g., depressions in the abundances of indigenous benthic infauna) are always expected. If any chemical exceeds its AET for a particular biological indicator, an adverse biological effect is predicted for that indicator. If all chemical concentrations are below their AET for a particular biological indicator then no adverse effect is predicted.

In this appendix, AET generation is described and the AET concept is discussed as it relates to the interpretation of chemical and biological data in field-collected sediments. AET generation is a conceptually simple process, and incorporates the complexity of biological-chemical interrelationships in the environment without relying upon *a priori* assumptions as to the mechanistic nature of these interrelationships. The concept of the AET is presented in this section with little reference to specific chemicals, specific biological tests, or specific chemical normalizations, because the approach is not inherently limited to specific subsets of these variables.

## DESCRIPTION OF THE AET APPROACH

The focus of the AET approach is to identify concentrations of contaminants that are associated exclusively with sediments exhibiting statistically significant biological effects relative to reference sediments. The calculation of AET for each chemical and biological indicator is straightforward:

1. **Collect "matched" chemical and biological effects data**--Conduct chemical and biological effects testing on subsamples of the same field sample (to avoid unaccountable losses of benthic organisms, benthic infaunal and chemical analyses are conducted on separate samples collected concurrently)

2. **Identify "impacted" and "nonimpacted" stations**--Statistically test the significance of adverse biological effects relative to suitable reference conditions for each sediment sample and biological indicator; suitable reference conditions are established by sediments containing very low or undetectable concentrations of any toxic chemicals

3. **Identify AET using only "nonimpacted" stations**--For each chemical, the AET can be identified for a given biological indicator as the highest detected concentration among sediment samples that do not exhibit statistically significant effects (if the chemical is undetected in all nonimpacted samples, no AET can be established for that chemical and biological indicator)

4. **Check for preliminary AET**--Verify that statistically significant biological effects are observed at a chemical concentration higher than the AET; otherwise the AET is only a preliminary minimum estimate (or may not exist).

5. Repeat Steps 1-4 for each biological indicator.

A pictorial representation of the AET approach for two example chemicals is presented in Figure A-1 based on results for a toxicity bioassay. Two subpopulations of all sediments analyzed for chemistry and subjected to a bioassay are represented by bars in the figure, and include:

- Sediments that did not exhibit statistically significant ($P>0.05$) toxicity relative to reference conditions ("nonimpacted" stations)

- Sediments that exhibited statistically significant ($P\leq0.05$) toxicity in bioassays relative to reference conditions ("impacted" stations).

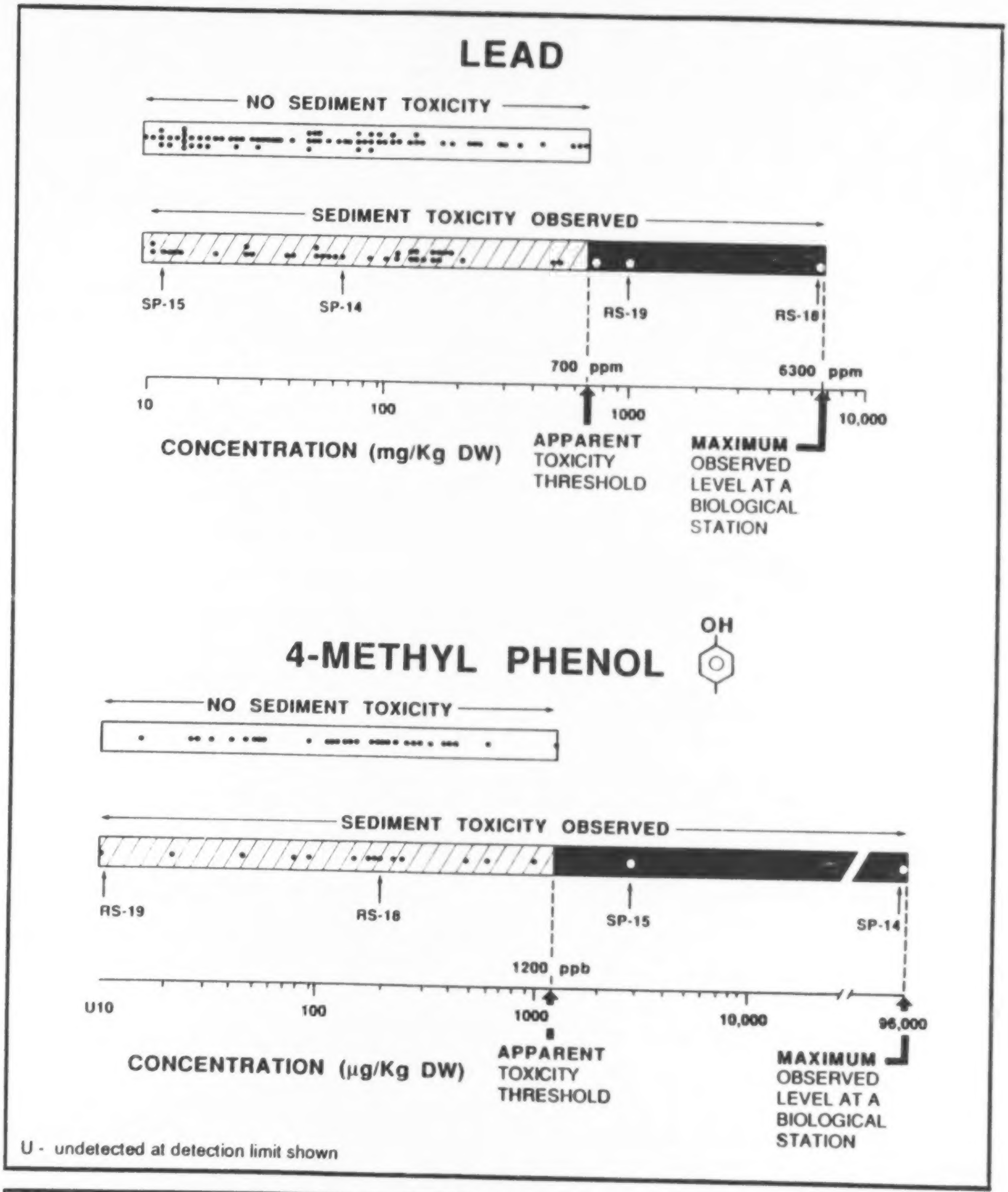
The horizontal axis in each figure represents sedimentary concentrations of chemicals (lead or 4-methylphenol) on a log scale. Dry weight normalized data are presented in Figure A-1, although the AET approach is not limited to any particular normalization. For the toxicity bioassay under consideration, the AET for lead is the highest lead concentration corresponding to sediments that did not exhibit significant toxicity (the top bar for lead in Figure A-1). Above this lead AET, significant toxicity was always observed in the data set. The AET for 4-methylphenol was determined analogously.

## INTERPRETATION OF AET

An AET corresponds to the sediment concentration of a chemical above which all samples for a particular biological indicator were observed to have adverse effects. Thus, the AET is based on non-contradictory evidence of biological effects. Data are treated in this manner to reduce the weight given to samples in which factors other than the contaminant examined (e.g., other contaminants, environmental variables) may be responsible for the biological effect.

### Relationships Among Chemical-Specific AET

Using Figure A-1 as an example, sediment from Station SP-14 exhibited severe toxicity, potentially related to a greatly elevated level of 4-methylphenol (7,400 times reference levels). The same sediment from Station SP-14 contained a relatively low concentration of lead that was well below the AET for lead (Figure A-1). Despite the toxic effects associated with the sample, sediments from many other stations with higher lead concentrations than SP-14 exhibited no statistically significant biological effects. These results were interpreted to suggest that the effects at Station SP-14 were potentially associated with 4-methylphenol (or a substance with a similar environmental distribution) but were less likely to be associated with lead. A converse argument can be made for lead and 4-methylphenol in sediments from Station RS-18. In this manner, the AET approach helps to identify measured chemicals that are potentially associated with observed effects at each biologically impacted site and eliminates from consideration chemicals that are far less likely to be associated with effects (i.e., the latter chemicals have been observed at higher concentrations at other sites without associated biological effects). Based on the results for lead and 4-methylphenol, effects at 4 of the 28 impacted sites shown in the figures may be associated with elevated concentrations of 4-methylphenol, and effects at 7 other sites may be associated with elevated concentrations of lead (or similarly distributed contaminants).



U - undetected at detection limit shown

Figure A-1. The AET approach applied to sediments tested for lead and 4-methyl phenol concentrations and toxicity response during bioassays.

These results illustrate that the occurrence of biologically impacted stations at concentrations below the AET of a single chemical does not imply that AET in general are not protective against biological effects, only that single chemicals may not account for all stations with biological effects. By developing AET for multiple chemicals, a high percentage of all stations with biological effects are accounted for with the AET approach (reliability results are presented in Section 3 of the main report).

AET can be expected to be more predictive when developed from a large, diverse database with wide ranges of chemical concentrations and a wide diversity of measured chemicals. Data sets that have large concentration gaps between stations and/or that do not cover a wide range of concentrations must be scrutinized carefully (e.g., to discern whether chemical concentrations in the data set exceed reference concentrations) before generation of AET is appropriate.

## Dose-Response Relationships and AET

The AET concept is consistent with empirical observations in the laboratory of dose response relationships between increasing concentrations of individual toxic chemicals and increasing biological effects. A simple hypothetical example of such single-chemical relationships is shown for chemicals X and Y in Figure A-2. In the example, data are shown for laboratory exposures of a test organism to sediment containing only increasing concentrations of chemical X, and independently, for exposures to sediment containing only increasing concentrations of chemical Y. The magnitude of toxic response in the example differs for the two chemicals, and occurs over two different concentration ranges. It is assumed that at some level of response, for example >25 percent, the two different responses can be distinguished from reference conditions (i.e., responses resulting from exposure to sediments containing very low or undetectable concentrations of any toxic chemicals).

These single-chemical relationships cannot be proven in the field because organisms are exposed to complex mixtures of chemicals in environmental samples. In addition, unrelated discharges from different sources can result in uncorrelated distributions of chemicals in environmental samples. To demonstrate the potential effects of these distributions, response data are shown in Figure A-3 for a random association of chemicals X and Y using the same concentration data as in Figure A-2. The data have been plotted according to increasing concentrations of chemical X and the same dose response relationship observed independently for the two chemicals in the laboratory has been assumed. The contributions of chemicals X and Y to the toxic response shown for these simple mixtures is intended only for illustration purposes to enable direct comparison to the relationships shown in Figure A-2, but is analogous to an additive toxic response. Other interactive effects are not considered in this example.

In Figure A-3, a significant response relative to reference conditions would result whenever elevated concentrations of either chemical X or chemical Y occurred in a sample. Because of the random association of Y with X in these samples, the significant responses would appear to occur randomly over the lower concentration range of chemical X. The classification of the responses shown in Figure A-3 into significant and nonsignificant groups (i.e., >25 percent response for either chemical) results in generation of Figure A-4.

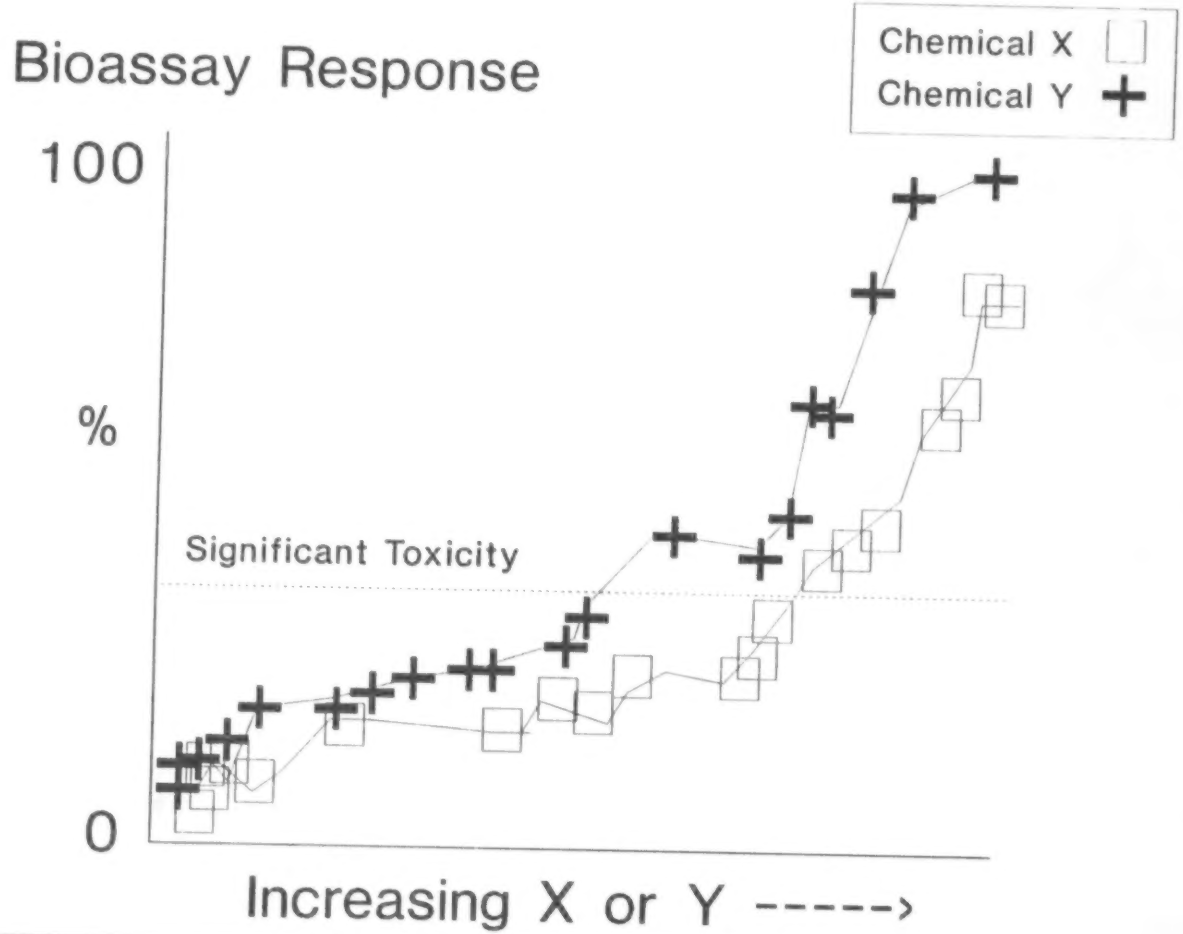


Figure A-2. Hypothetical example of dose-response relationship resulting from laboratory exposure to single chemicals X and Y.

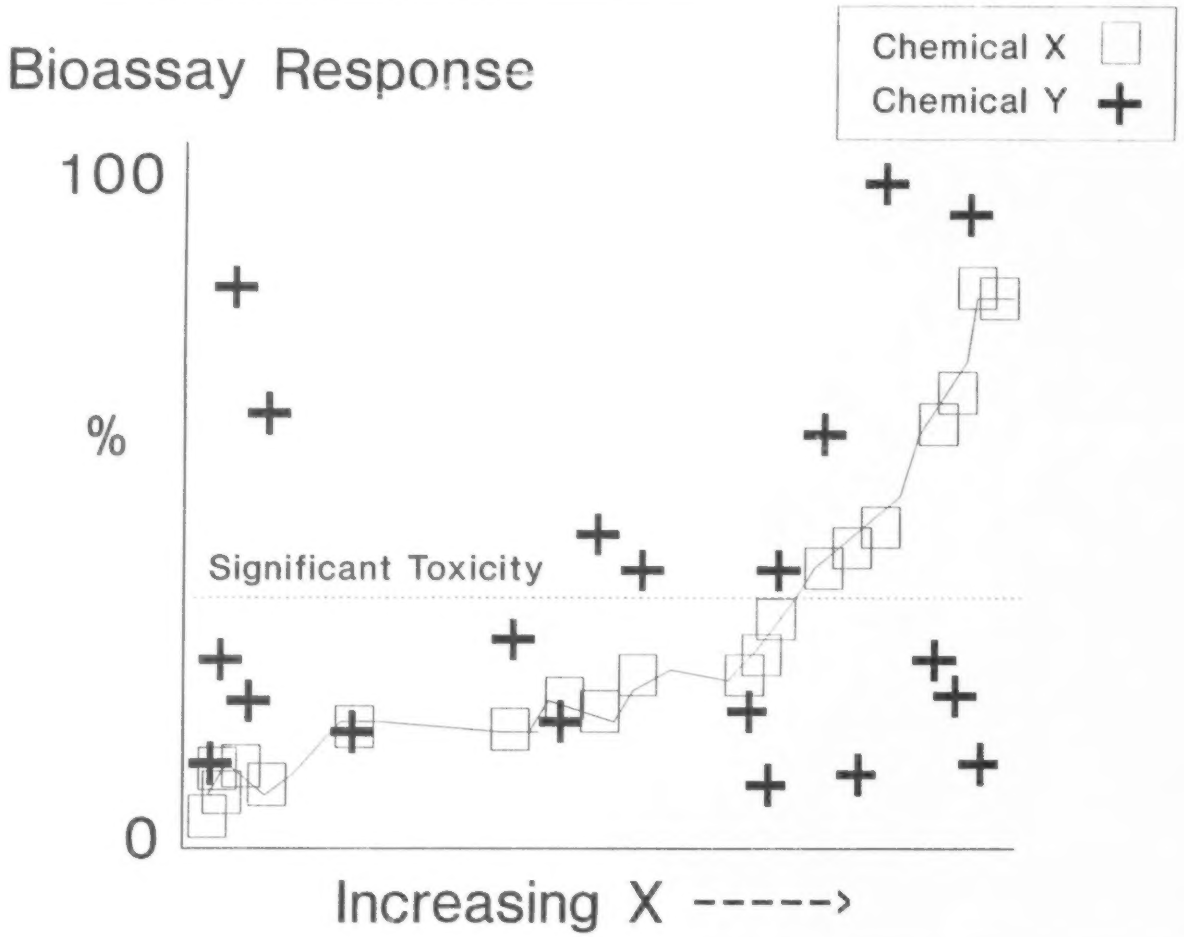


Figure A-3. Hypothetical example of toxic response resulting from exposure to environmental samples of sediment contaminated with chemicals X and Y.

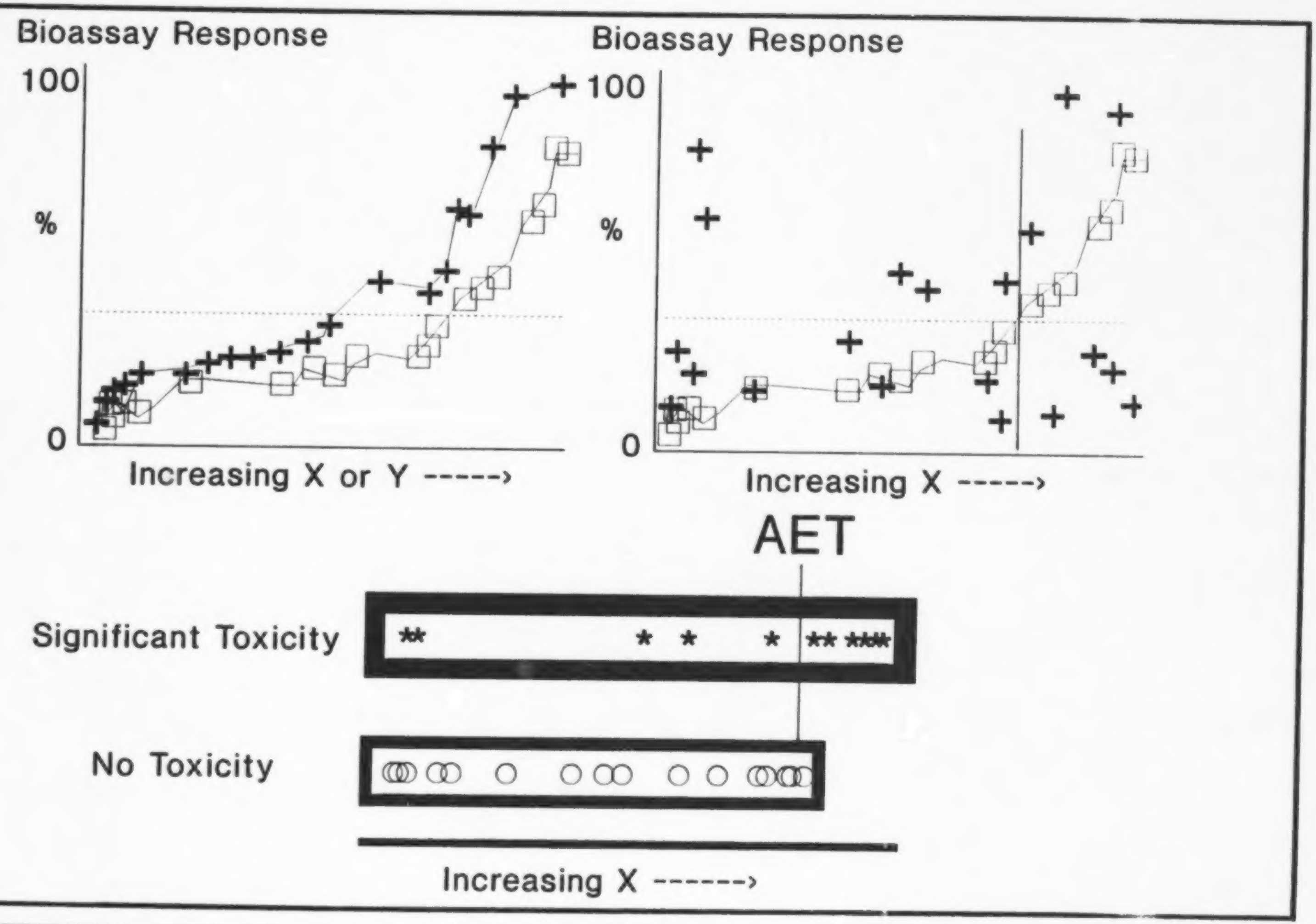


Figure A-4. Hypothetical example of AET calculation for chemical X based on classification of significant and nonsignificant responses for environmental samples contaminated with both chemicals X and Y. [Previous Figures A-2 and A-3 are also shown for comparison; dashed line indicates level of significant toxicity]

Figure A-4 represents how the actual environmental results would appear when ranked according to concentration of chemical X using these same data. Below the AET for chemical X, significant toxicity is produced by elevated concentrations of chemical Y, which is randomly associated with the distribution of chemical X. Above the AET for chemical X, significant toxicity is always produced by elevated concentrations of chemical X although in some samples, elevated concentrations of chemical Y also contribute to the overall toxicity. The AET for chemical X corresponds conceptually, in this simple example, to the concentration in Figure A-2 at which a significant difference in response was observed in the laboratory for chemical X.

In environmental samples that contain complex mixtures of chemicals, a monotonic dose-response relationship such as in this simple two-chemical example may not always apply. For example, a consistently increasing biological response may not always occur at increasing concentrations of a chemical above its AET. Such observations could indicate that the AET is coincidental (i.e., that the observed toxicity in some or all samples above the AET is unrelated to the presence of that chemical), or that changing environmental factors in samples exceeding an AET obscure a monotonic dose-response relationship. Such factors are discussed in the following section.

### Influence of Environmental Factors on AET Interpretation

Although the AET concept is simple, the generation of AET values based on environmental data incorporates many complex biological-chemical interrelationships. For example, the AET approach incorporates the net effects of the following factors that may be important in field-collected sediments:

- Interactive effects of chemicals (e.g., synergism, antagonism, and additivity)
- Unmeasured chemicals and other unmeasured, potentially adverse variables
- Matrix effects and bioavailability (i.e., phase associations between contaminants and sediments that affect bioavailability of the contaminants, such as the incorporation of PAH in soot particles).

The AET approach cannot distinguish and quantify the contributions of interactive effects, unmeasured chemicals, or matrix effects in environmental samples, but AET values may be influenced by these factors. To the extent that the samples used to generate AET are representative of samples for which AET are used to predict effects, the above environmental factors may not detract from the predictive reliability of AET. Alternatively, the infrequent occurrence of the above environmental factors in a data set used to generate AET could detract from the predictive reliability of those AET values. If confounding environmental factors render the AET approach unreliable, this should be evident from validation tests in which biological effects are predicted in environmental samples. Tests of AET values generated from Puget Sound data (see Section 3 of the main report) indicate that the approach is relatively reliable in predicting biological effects despite the potential uncertainties of confounding environmental factors.

Although the above environmental factors can influence the *generation* of field-based sediment quality values such as AET, they also may influence the *application* of all sediment quality value approaches for the prediction of adverse biological effects. For example, sediment quality values based on laboratory sediment bioassays spiked with single chemicals would not be susceptible to the effects of the environmental factors listed above; however, in applying such values to field-collected samples, predictions of biological effects could be less successful to the extent that interactive effects, unmeasured chemicals, and matrix effects occur in the environment.

The nature of the relationships between AET values and confounding environmental factors is discussed in the remainder of this section.

**Interactive Effects and AET** -- AET uncertainty is increased by the possibility of interactive effects; the increase in uncertainty is expected to be less pronounced when large data sets collected from diverse areas are used to generate AET. Additivity and synergism can produce a comparatively low AET for a given chemical by causing impacts at concentrations that would not cause impacts in the absence of these interactive effects. This would effectively reduce the pool of nonimpacted stations used to generate AET. This effect should be reduced if a diverse database is used such that chemicals occur over a wide range of concentrations at stations where additivity and synergism are not operative. For chemicals that covary regularly in the environment (e.g., fluoranthene and pyrene), even a large, diverse database will not reduce the effects of additivity and/or synergism on AET generation. The resulting AET values for such chemicals may be reliable in predicting biological effects in environmental samples although not representative of the toxicities of the chemicals acting independently.

Antagonism will produce comparatively high AET values if (and only if) the AET is established at a station where antagonism occurs. A large, diverse database could not rectify this elevation of AET if the station at which antagonism occurred was the nonimpacted station with the highest concentration (i.e., the station setting an AET). An AET set by a station at which antagonism occurred would not be representative of the toxicity of the chemical acting independently. Hence, if antagonism did not occur widely, such antagonistic effects would cause the AET to be less sensitive in predicting adverse effects in the environment.

Empirical approaches such as the AET do not provide a means for characterizing interactive effects. Only laboratory-spiked sediment bioassays offer a systematic and reliable method for identifying and quantifying additivity, synergism, and antagonism. Unfortunately, a great deal of research effort would be required to test the range of chemicals potentially occurring in the environment (both individually and in combination) and a sufficiently wide range of organisms to establish criteria. In addition, the applicability of bioassays conducted with laboratory-spiked sediments to environmentally-contaminated sediments requires further testing.

**Unmeasured Chemicals and AET**--Another source of uncertainty for AET and other field-based approaches is the possibility of effects being caused by unmeasured, covarying chemicals. Such chemicals would not be expected to substantially decrease the ability of AET to predict biologically impacted stations (excluding interactive effects discussed above). If an unmeasured chemical (or group of chemicals) varies consistently in the environment with a measured chemical, then the AET established for the measured contaminant will indirectly apply to, or result in the management of, the unmeasured contaminant. In such cases, a measured contaminant would act as a surrogate for an unmeasured contaminant (or group of unmeasured contaminants). Because all potential contaminants cannot be measured routinely, management strategies must rely to some extent on "surrogate" chemicals.

If an unmeasured toxic chemical (or group of chemicals) does not always covary with a measured chemical (e.g., if a certain industry releases an unusual mixture of contaminants), the effect should be mitigated if a sufficiently large and diverse data set is used to establish AET. Use of a large data set comprising samples from a variety of areas with wide-ranging chemical concentrations would decrease the likelihood that an unrealistically low AET would be set. Because AET are set by the highest concentration of a given chemical in samples without observed biological effects, AET will not be affected by less contaminated samples in which unmeasured contaminants cause biological effects.

If an unmeasured toxic chemical does not covary with any of the measured chemicals, it is unlikely that the AET (or any other chemical-specific approach) could predict impacts at stations where the chemical is inducing toxic effects. The frequency of occurrence of stations with biological effects but no chemicals exceeding AET is the subject of validation tests (see Section 3 of the main report).

**Matrix Effects and Bioavailability**--Geochemical associations of contaminants with sediments that reduce bioavailability of those contaminants would affect AET analogously to antagonistic effects (i.e., they would increase AET relative to sediments in which this factor was not operative). Sediment matrices observed in Puget Sound that may reduce bioavailability of certain contaminants include slag material (containing high concentrations of various metals and metalloids, such as copper and arsenic) and coal or soot (which may contain high concentrations of largely unavailable PAH, as opposed to oil or creosote, in which PAH would be expected to be far more bioavailable; e.g., Farrington and Teal 1982). Many kinds of matrices may occur in the environment and a large proportion may be difficult to classify based upon appearance or routinely measured sediment variables. Hence, the use of matrix-specific data sets to generate AET, although desirable, would be difficult to implement.

To address this concern from a technical perspective (i.e., representativeness of data used in AET generation), the AET database could be screened for sediment with chemical concentrations that are anomalously high relative to those in other nonimpacted sediments from different geographic areas. From a management perspective, this guideline would generate more protective (sensitive) sediment quality standards that may also be less efficient in only identifying problem sediments. These sediments would be considered nonrepresentative and not used in AET generation unless and until additional data could substantiate that they are representative. Such data treatment methods are discussed in Volume I, Appendix C of this report.

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## TABLE B-1. SUMMARY OF SURVEYS USED TO EVALUATE PSDDA MAXIMUM AND SCREENING LEVEL VALUES

| Survey | Survey Name | Date | Responsible Agency |
|---|---|---|---|
| ALKI | 1984 Alki Pt. Survey | 5/84 | METRO |
| CBBLAIR | Commencement Bay Blair Waterway Dredging Survey | 6/84 | Port of Tacoma |
| CBMSQS | Commencement Bay RI Main Sediment Quality Survey | 3/84 | Washington Dept. of Ecology, U.S. EPA, Region 10 |
| DUWRIV1 | Duwamish River I Dredged Material Characterization Survey | 4/85 | U.S. Army Corps of Engineers |
| DUWRIV2 | Duwamish River II Dredged Material Characterization Survey | 9/85 | U.S. Army Corps of Engineers |
| EBCHEM | Elliott Bay Toxics Action Plan | 9/85 | U.S. EPA, Region 10 |
| EHCHEM | Eagle Harbor Preliminary Survey | 6/85 | Washington Dept. of Ecology |
| EIGHTBAY | Puget Sound Eight-Bay Reconnaissance Survey | 5/84 | U.S. EPA, Region 10 |
| EVCHEM | Everett Harbor Toxics Action Plan | 9/86 | U.S. EPA, Region 10 |
| EVERETT1 | Navy home-port EIS project | /85 | U.S. Navy |
| TPPS3AB | Toxics Pretreatment Planning Study, Phase III A & B | 3/82<br>7/82 | METRO |

BIOLIST.TXT

## TABLE B-2. BIOLOGICAL EFFECTS STATIONS USED TO EVALUATE PSDDA MAXIMUM AND SCREENING LEVEL VALUES

The biological effects listed are:

| | |
|---|---|
| AMPT | Amphipod toxicity AET. |
| BENA | Benthic infauna abundance AET. |
| MICB | Microtox bioassay AET. |
| OYST | Oyster larvae toxicity AET. |

| Survey | Station | Date | Sample | AMPT | BENA | MICB | OYST |
|---|---|---|---|---|---|---|---|
| ALKI | AP-01 | 05/25/84 | AP-01 | | NO HITa | | |
| ALKI | AP-02 | 05/25/84 | AP-02 | | NO HIT | | |
| ALKI | AP-03 | 05/25/84 | AP-03 | | NO HIT | | |
| ALKI | AP-04 | 05/25/84 | AP-04 | | HIT | | |
| ALKI | AP-05 | 05/25/84 | AP-05 | | NO HIT | | |
| ALKI | AP-06 | 05/25/84 | AP-06 | | NO HIT | | |
| ALKI | AP-07 | 05/25/84 | AP-07 | | NO HIT | | |
| ALKI | PW-01 | 05/26/84 | PW-01 | | NO HIT | | |
| ALKI | PW-02 | 05/26/84 | PW-02 | | NO HIT | | |
| ALKI | PW-03 | 05/26/84 | PW-03 | | NO HIT | | |
| ALKI | PW-04 | 05/26/84 | PW-04 | | NO HIT | | |

*Benthic Infauna Abundance was the only biological effect tested in the Alki survey.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CBBLAIR | B03 | 06/01/84 | B03 | NO HIT | NO HIT | | NO HIT |
| CBBLAIR | B04 | 06/01/84 | B04 | NO HIT | NO HIT | | NO HIT |
| CBBLAIR | B09 | 06/01/84 | B09 | NO HITa | NO HIT | | NO HIT |
| CBBLAIR | B10 | 06/01/84 | B10 | NO HITa | NO HIT | | HIT |
| CBBLAIR | B12 | 06/01/84 | B12 | NO HITa | NO HIT | | NO HIT |
| CBBLAIR | B15 | 06/01/84 | B15 | HIT | NO HIT | | NO HIT |

*The Amphipod and Oyster Larvae Bioassays, and Benthic Infauna Abundance were the only biological effects tested in the CBBLAIR Survey.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CBMSQS | BL-11 | 01/01/84 | BL-11 | NO HIT | NO HIT | NO HIT | NO HIT |
| CBMSQS | BL-13 | 01/01/84 | BL-13 | NO HITa | NO HIT | HIT | NO HIT |
| CBMSQS | BL-21 | 01/01/84 | BL-21 | NO HIT | NO HIT | NO HIT | NO HIT |
| CBMSQS | BL-25 | 01/01/84 | BL-25 | HIT | NO HIT | NO HIT | NO HIT |
| CBMSQS | BL-28 | 01/01/84 | BL-28 | NO HIT | NO HIT | NO HIT | NO HIT |
| CBMSQS | BL-31 | 01/01/84 | BL-31 | NO HITa | NO HIT | HIT | NO HIT |
| CBMSQS | CI-11 | 01/01/84 | CI-11 | HIT | HIT | HIT | HIT |
| CBMSQS | CI-13 | 01/01/84 | CI-13 | NO HITa | HIT | HIT | HIT |
| CBMSQS | CI-16 | 01/01/84 | CI-16 | b | HIT | HIT | HIT |
| CBMSQS | CI-17 | 01/01/84 | CI-17 | NO HITa | HIT | HIT | NO HIT |
| CBMSQS | CI-20 | 01/01/84 | CI-20 | HIT | NO HIT | NO HIT | HIT |
| CBMSQS | CI-22 | 01/01/84 | CI-22 | NO HITa | NO HIT | NO HIT | NO HIT |
| CBMSQS | CR-11 | 01/01/84 | CR-11 | NO HIT | NO HIT | NO HIT | NO HIT |
| CBMSQS | CR-12 | 01/01/84 | CR-12 | NO HIT | NO HIT | NO HIT | NO HIT |
| CBMSQS | CR-13 | 01/01/84 | CR-13 | NO HIT | NO HIT | NO HIT | NO HIT |
| CBMSQS | CR-14 | 01/01/84 | CR-14 | NO HIT | NO HIT | NO HIT | NO HIT |
| CBMSQS | HY-12 | 01/01/84 | HY-12 | b | NO HIT | HIT | HIT |
| CBMSQS | HY-14 | 01/01/84 | HY-14 | NO HIT | HIT | HIT | NO HIT |
| CBMSQS | HY-17 | 01/01/84 | HY-17 | NO HITa | HIT | HIT | HIT |
| CBMSQS | HY-22 | 01/01/84 | HY-22 | HIT | HIT | HIT | HIT |

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CBMSQS    HY-23      01/01/84  HY-23             HIT       HIT       HIT       HIT
CBMSQS    HY-24      01/01/84  HY-24             NO HITa   HIT       HIT       NO HIT
CBMSQS    HY-28      01/01/84  HY-28             NO HIT    HIT       NO HIT    NO HIT
CBMSQS    HY-32      01/01/84  HY-32             NO HITa   HIT       NO HIT    NO HIT
CBMSQS    HY-37      01/01/84  HY-37             NO HITa   HIT       HIT       NO HIT
CBMSQS    HY-42      01/01/84  HY-42             HIT       HIT       HIT       NO HIT
CBMSQS    HY-43      01/01/84  HY-43             NO HITa   HIT       HIT       NO HIT
CBMSQS    HY-44      01/01/84  HY-44             NO HITa   NO HIT    NO HIT    NO HIT
CBMSQS    HY-47      01/01/84  HY-47             HIT       HIT       HIT       HIT
CBMSQS    HY-50      01/01/84  HY-50             NO HITa   NO HIT    HIT       NO HIT
CBMSQS    MD-12      01/01/84  MD-12             NO HIT    HIT       NO HIT    NO HIT
CBMSQS    MI-11      01/01/84  MI-11             HIT       NO HIT    NO HIT    NO HIT
CBMSQS    MI-13      01/01/84  MI-13             NO HIT    NO HIT    HIT       NO HIT
CBMSQS    MI-15      01/01/84  MI-15             HIT       NO HIT    HIT       NO HIT
CBMSQS    RS-12      01/01/84  RS-12             NO HIT    NO HIT    NO HIT    NO HIT
CBMSQS    RS-13      01/01/84  RS-13             HIT       NO HIT    NO HIT    HIT
CBMSQS    RS-14      01/01/84  RS-14             NO HITa   NO HITa   NO HIT    NO HIT
CBMSQS    RS-18      01/01/84  RS-18             HIT       HIT       HIT       HIT
CBMSQS    RS-19      01/01/84  RS-19             HIT       HIT       HIT       HIT
CBMSQS    RS-20      01/01/84  RS-20             NO HIT    HIT       HIT       NO HIT
CBMSQS    RS-22      01/01/84  RS-22             NO HIT              NO HIT    NO HIT
CBMSQS    RS-24      01/01/84  RS-24             HIT                 NO HIT    NO HIT
CBMSQS    SI-11      01/01/84  SI-11             NO HITa   HIT       HIT       NO HIT
CBMSQS    SI-12      01/01/84  SI-12             HIT       HIT       HIT       NO HIT
CBMSQS    SI-15      01/01/84  SI-15             HIT       NO HITa   NO HIT    NO HIT
CBMSQS    SP-11      01/01/84  SP-11             NO HIT    HIT       HIT       NO HIT
CBMSQS    SP-12      01/01/84  SP-12             NO HITa   NO HIT    HIT       HIT
CBMSQS    SP-14      01/01/84  SP-14             HIT       HIT       HIT       HIT
CBMSQS    SP-15      01/01/84  SP-15             HIT       HIT       HIT       HIT
CBMSQS    SP-16      01/01/84  SP-16             HIT       HIT       HIT       HIT

DUWRIV1   DR-01      04/15/85  DR-01             NO HIT
DUWRIV1   DR-02      04/15/85  DR-02             NO HIT
DUWRIV1   DR-03      04/15/85  DR-03             NO HIT
DUWRIV1   DR-04      04/15/85  DR-04             NO HIT
DUWRIV1   DR-05      04/15/85  DR-05             NO HIT
DUWRIV1   DR-06      04/15/85  DR-06             NO HIT
DUWRIV1   DR-07      04/15/85  DR-07             HIT
DUWRIV1   DR-08      04/15/85  DR-08             HIT
DUWRIV1   SQ-09      04/19/85  SQ-09             NO HIT

DUWRIV2   DR-10      07/01/85  CA1               HIT
DUWRIV2   DR-11      07/01/85  CA2               HIT
DUWRIV2   DR-12      07/01/85  CA3               NO HIT
DUWRIV2   DR-13      07/01/85  CB1               NO HIT
DUWRIV2   DR-14      07/01/85  CB2               NO HIT
DUWRIV2   DR-15      07/01/85  CB3               NO HIT
DUWRIV2   DR-16      07/01/85  CB4               HIT
DUWRIV2   DR-17      07/01/85  CB5               NO HIT
DUWRIV2   DR-18      07/01/85  CC1               NO HIT
DUWRIV2   DR-19      07/01/85  CC2               NO HIT
DUWRIV2   DR-20      07/01/85  CC3               NO HIT
DUWRIV2   DR-21      07/01/85  CC4               NO HIT
DUWRIV2   DR-22      07/01/85  CC5               NO HIT
DUWRIV2   DR-23      07/01/85  CD1               NO HIT
DUWRIV2   DR-24      07/01/85  CD2               NO HIT
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DUWRIV2 DR-25    07/01/85 CE1         HIT
DUWRIV2 DR-26    07/01/85 CE2         HIT
DUWRIV2 DR-27    07/01/85 CE3         HIT
DUWRIV2 DR-28    07/01/85 CF1         NO HIT
DUWRIV2 DR-29    07/01/85 CF2         HIT
DUWRIV2 DR-30    07/01/85 CF3         NO HIT
DUWRIV2 DR-31    07/01/85 CF4         NO HIT
DUWRIV2 DR-32    07/01/85 CF5         NO HIT
DUWRIV2 DR-33    07/01/85 CG1         NO HIT
DUWRIV2 DR-34    07/01/85 CG2         NO HIT
DUWRIV2 DR-35    07/01/85 CG3         NO HITa
DUWRIV2 DR-36    07/01/85 CG4         NO HIT
DUWRIV2 DR-37    07/01/85 CG5         NO HIT
DUWRIV2 DR-38    07/01/85 CH1         NO HIT
DUWRIV2 DR-39    07/01/85 CW/A1       NO HIT
DUWRIV2 SQ-21    07/01/85 SEQUIM      NO HIT

 *Amphipod toxicity was the only biological effect tested in the DUWRIV1 and DUWRIV2 surveys.

EBCHEM  AB-01    09/26/85 AB-01       HIT            b
EBCHEM  AB-02    09/26/85 AB-02       NO HIT  NO HIT
EBCHEM  AB-03    09/26/85 AB-03       NO HIT  HIT
EBCHEM  AB-04    09/26/85 AB-04       NO HIT  NO HIT
EBCHEM  DR-01    09/30/85 DR-01       NO HIT
EBCHEM  DR-02    09/30/85 DR-02       HIT
EBCHEM  DR-03    09/30/85 DR-03       NO HIT
EBCHEM  DR-04    09/30/85 DR-04       NO HIT
EBCHEM  DR-05    09/30/85 DR-05           c
EBCHEM  DR-06    10/09/85 DR-06       NO HIT
EBCHEM  DR-07    09/30/85 DR-07       NO HIT
EBCHEM  DR-08    09/30/85 DR-08           c
EBCHEM  DR-09    09/30/85 DR-09       NO HIT
EBCHEM  DR-10    09/30/85 DR-10           b
EBCHEM  DR-11    09/30/85 DR-11       NO HIT
EBCHEM  DR-12    09/30/85 DR-12           b
EBCHEM  DR-13    09/30/85 DR-13       HIT
EBCHEM  DR-14    09/30/85 DR-14       HIT
EBCHEM  DR-15    09/30/85 DR-15       HIT
EBCHEM  DR-16    09/30/85 DR-16       HIT
EBCHEM  DR-17    09/30/85 DR-17       NO HIT
EBCHEM  DR-25    10/10/85 DR-25       HIT
EBCHEM  EW-01    10/09/85 EW-01       NO HIT
EBCHEM  EW-02    10/04/85 EW-02       HIT     HIT
EBCHEM  EW-03    10/04/85 EW-03           c   NO HIT
EBCHEM  EW-04    10/14/85 EW-04       HIT     HIT
EBCHEM  EW-05    10/14/85 EW-05       HIT     HIT
EBCHEM  EW-05    10/14/85 EW-05       HIT     HIT
EBCHEM  EW-06    10/04/85 EW-06       HIT     HIT
EBCHEM  EW-07    10/14/85 EW-07       HIT     HIT
EBCHEM  EW-08    10/14/85 EW-08       HIT     HIT
EBCHEM  EW-09    10/14/85 EW-09       HIT     HIT
EBCHEM  EW-10    10/14/85 EW-10       HIT     NO HIT
EBCHEM  EW-11    10/14/85 EW-11       HIT     HIT
EBCHEM  EW-12    10/15/85 EW-12       NO HIT  NO HIT
EBCHEM  EW-13    10/15/85 EW-13       NO HIT  NO HIT
EBCHEM  EW-14    10/15/85 EW-14       NO HIT  NO HIT
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BIOLIST.TXT


EBCHEM    EW-15    10/15/85  EW-15        NO HIT    NO HIT
EBCHEM    EW-16    10/15/85  EW-16        HIT       NO HIT
EBCHEM    KG-01    09/25/85  KG-01        NO HIT    HIT
EBCHEM    KG-02    10/09/85  KG-02        HIT
EBCHEM    KG-03    09/25/85  KG-03        HIT       NO HIT
EBCHEM    KG-04    10/09/85  KG-04        NO HIT
EBCHEM    KG-05    09/30/85  KG-05        HIT       HIT
EBCHEM    KG-06    09/30/85  KG-06        NO HIT    HIT
EBCHEM    KG-07    09/30/85  KG-07        NO HIT    HIT
EBCHEM    KG-08    10/01/85  KG-08        NO HIT    HIT
EBCHEM    KG-09    10/01/85  KG-09        HIT       NO HIT
EBCHEM    KG-10    10/08/85  KG-10        HIT
EBCHEM    KG-11    10/01/85  KG-11        HIT       HIT
EBCHEM    MG-01    09/26/85  MG-01        NO HIT    HIT
EBCHEM    MG-02    09/26/85  MG-02        NO HIT    HIT
EBCHEM    MG-03    09/26/85  MG-03        NO HIT    HIT
EBCHEM    MG-04    09/26/85  MG-04        NO HIT    HIT
EBCHEM    NH-01    10/15/85  NH-01        NO HIT    HIT
EBCHEM    NH-02    10/15/85  NH-02        HIT       HIT
EBCHEM    NH-03    10/16/85  NH-03        HIT       HIT
EBCHEM    NH-04    10/15/85  NH-04        HIT       HIT
EBCHEM    NH-05    10/15/85  NH-05        HIT       HIT
EBCHEM    NH-06    10/16/85  NH-06        HIT       HIT
EBCHEM    NH-07    10/09/85  NH-07        NO HIT
EBCHEM    NH-08    10/16/85  NH-08        HIT       HIT
EBCHEM    NH-09    10/16/85  NH-09        HIT       NO HIT
EBCHEM    NH-10    10/08/85  NH-10        NO HIT
EBCHEM    NH-11    10/15/85  NH-11        HIT       HIT
EBCHEM    NS-01    10/08/85  NS-01        HIT
EBCHEM    NS-02    09/27/85  NS-02        NO HIT    NO HIT
EBCHEM    NS-03    10/04/85  NS-03        NO HIT    NO HIT
EBCHEM    NS-04    10/08/85  NS-04              c
EBCHEM    NS-05    10/04/85  NS-05        NO HIT    NO HIT
EBCHEM    NS-06    09/27/85  NS-06              b   HIT
EBCHEM    NS-07    10/04/85  NS-07        HIT       NO HIT
EBCHEM    NS-08    09/26/85  NS-08        HIT       HIT
EBCHEM    PS-01    10/12/85  PS-01        NO HIT    NO HIT
EBCHEM    PS-01    10/12/85  PS-01        NO HIT    NO HIT
EBCHEM    PS-02    10/12/85  PS-02        NO HIT    NO HIT
EBCHEM    PS-03    10/12/85  PS-03        NO HIT    NO HIT
EBCHEM    PS-04    10/12/85  PS-04        NO HIT    NO HIT
EBCHEM    SS-01    10/16/85  SS-01        NO HIT    NO HIT
EBCHEM    SS-03    10/04/85  SS-03        HIT       HIT
EBCHEM    SS-04    10/04/85  SS-04              b   HIT
EBCHEM    SS-05    10/03/85  SS-05        NO HIT    NO HIT
EBCHEM    SS-05    10/03/85  SS-05        NO HIT    NO HIT
EBCHEM    SS-06    10/03/85  SS-06        HIT       HIT
EBCHEM    SS-07    10/03/85  SS-07        HIT       NO HIT
EBCHEM    SS-08    09/27/85  SS-08        HIT       HIT
EBCHEM    SS-09    09/27/85  SS-09        HIT       HIT
EBCHEM    SS-10    09/27/85  SS-10              b         b
EBCHEM    SS-11    09/27/85  SS-11        NO HIT    NO HIT
EBCHEM    SS-12    09/27/85  SS-12        NO HIT    NO HIT
EBCHEM    WW-01    10/01/85  WW-01        NO HIT    HIT
EBCHEM    WW-02    10/09/85  WW-02        HIT
EBCHEM    WW-03    10/01/85  WW-03        NO HIT    HIT
EBCHEM    WW-04     10/01/85  WW-04         NO HIT    HIT
EBCHEM    WW-05     10/01/85  WW-05         NO HIT    HIT
EBCHEM    WW-06     10/01/85  WW-06         NO HIT    HIT
EBCHEM    WW-06     10/01/85  WW-06         NO HIT    HIT
EBCHEM    WW-08     10/01/85  WW-08         HIT       HIT
EBCHEM    WW-09     10/02/85  WW-09         HIT       HIT
EBCHEM    WW-10     10/02/85  WW-10         NO HIT    HIT
EBCHEM    WW-11     10/02/85  WW-11         HIT       HIT
EBCHEM    WW-12     10/02/85  WW-12         HIT       HIT
EBCHEM    WW-13     10/02/85  WW-13         NO HIT    NO HIT
EBCHEM    WW-14     10/02/85  WW-14              b     HIT
EBCHEM    WW-15     10/08/85  WW-15         NO HIT
EBCHEM    WW-16     10/02/85  WW-16         NO HIT    HIT
EBCHEM    WW-17     10/03/85  WW-17         NO HIT    HIT
EBCHEM    WW-18     10/03/85  WW-18         NO HIT    HIT
EBCHEM    WW-19     10/03/85  WW-19         NO HIT    HIT
EBCHEM    WW-20     10/03/85  WW-20         NO HIT    HIT

EHCHEM    BH-01     06/01/85  B1            NO HIT    NO HIT
EHCHEM    BH-02     06/01/85  B1            NO HIT    NO HIT
EHCHEM    EH-01     06/01/85  B1            NO HIT    NO HIT
EHCHEM    EH-02     06/01/85  B1            NO HIT    HIT
EHCHEM    EH-03     06/01/85  V6            NO HIT    HIT
EHCHEM    EH-05     06/01/85  V1            NO HIT    HIT
EHCHEM    EH-06     06/01/85  V6            NO HIT    HIT
EHCHEM    EH-08     06/01/85  V1            HIT       HIT
EHCHEM    EH-15     06/01/85  V1            NO HIT    HIT
EHCHEM    EH-16     06/01/85  V1            NO HIT    HIT
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*Amphipod toxicity and benthic infauna abundance were the only biological effects tested in the EBCHEM and EHCHEM surveys.

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EIGHTBAY  BH-03     01/01/82  BH-03         NO HIT
EIGHTBAY  BH-04     01/01/82  BH-04         NO HIT
EIGHTBAY  BH-05     01/01/82  BH-05         HIT
EIGHTBAY  BH-07     01/01/82  BH-07         NO HIT
EIGHTBAY  BH-11     01/01/82  BH-11         NO HIT
EIGHTBAY  BH-12     01/01/82  BH-12         NO HIT
EIGHTBAY  BH-23     01/01/82  BH-23         HIT
EIGHTBAY  BH-24     01/01/82  BH-24         NO HIT
EIGHTBAY  CS-01     01/01/82  CS-01         HIT
EIGHTBAY  CS-11     01/01/82  CS-11         HIT
EIGHTBAY  CS-15     01/01/82  CS-15         HIT
EIGHTBAY  CS-17     01/01/82  CS-17         HIT
EIGHTBAY  DB-01     01/01/82  DB-01         NO HIT
EIGHTBAY  DB-05     01/01/82  DB-05         NO HIT
EIGHTBAY  DB-07     01/01/82  DB-07         HIT
EIGHTBAY  DB-15     01/01/82  DB-15         HIT
EIGHTBAY  EL-09     01/01/82  EL-09         NO HIT
EIGHTBAY  EL-10     01/01/82  EL-10         NO HIT
EIGHTBAY  EL-12     01/01/82  EL-12         NO HIT
EIGHTBAY  EL-17     01/01/82  EL-17         NO HIT
EIGHTBAY  EL-20     01/01/82  EL-20         NO HIT
EIGHTBAY  EL-22     01/01/82  EL-22         NO HIT
EIGHTBAY  EL-23     01/01/82  EL-23         NO HIT
EIGHTBAY  EL-24     01/01/82  EL-24         NO HIT
EIGHTBAY  EV-01     01/01/82  EV-01          HIT
EIGHTBAY  EV-02     01/01/82  EV-02          HIT
EIGHTBAY  EV-03     01/01/82  EV-03          HIT
EIGHTBAY  EV-04     01/01/82  EV-04          HIT
EIGHTBAY  EV-05     01/01/82  EV-05          HIT
EIGHTBAY  EV-06     01/01/82  EV-06          NO HIT
EIGHTBAY  EV-07     01/01/82  EV-07          NO HIT
EIGHTBAY  EV-11     01/01/82  EV-11          HIT
EIGHTBAY  SC-06     01/01/82  SC-06          HIT
EIGHTBAY  SC-07     01/01/82  SC-07          NO HIT
EIGHTBAY  SC-08     01/01/82  SC-08          HIT
EIGHTBAY  SC-14     01/01/82  SC-14          HIT
EIGHTBAY  SC-17     01/01/82  SC-17          HIT
EIGHTBAY  SC-18     01/01/82  SC-18          HIT
EIGHTBAY  SC-19     01/01/82  SC-19          NO HITa
EIGHTBAY  SC-20     01/01/82  SC-20          HIT
EIGHTBAY  SM-01     01/01/82  SM-01          HIT
EIGHTBAY  SM-03     01/01/82  SM-03          HIT
EIGHTBAY  SM-07     01/01/82  SM-07          HIT
EIGHTBAY  SM-20     01/01/82  SM-20          HIT
EIGHTBAY  SQ-14     01/01/82  SQ-14          NO HIT
EIGHTBAY  SQ-17     01/01/82  SQ-17          NO HIT
EIGHTBAY  SQ-18     01/01/82  SQ-18          NO HIT
EIGHTBAY  SQ-20     01/01/82  SQ-20          NO HIT
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*Amphipod toxicity was the only biological effect tested in the EIGHTBAY survey.

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EVCHEM    ES-01     10/06/86  ES-01G         NO HIT
EVCHEM    ES-02     10/06/86  ES-02G         NO HIT
EVCHEM    ES-03     10/06/86  ES-03G         NO HIT
EVCHEM    EW-01     10/07/86  EW-01G         HIT       HIT
EVCHEM    EW-04     09/30/86  EW-04G         HIT       HIT
EVCHEM    EW-07     09/30/86  EW-07G         HIT       HIT
EVCHEM    EW-10     10/01/86  EW-10G         HIT       HIT
EVCHEM    EW-12     10/01/86  EW-12G         NO HIT    HIT
EVCHEM    EW-14     10/01/86  EW-14G               c   HIT
EVCHEM    NG-01     10/02/86  NG-01G         NO HIT    NO HIT
EVCHEM    NG-02     10/02/86  NG-02G         NO HIT    HIT
EVCHEM    NG-03     10/02/86  NG-03G         NO HIT    HIT
EVCHEM    NG-04     10/02/86  NG-04G         HIT       HIT
EVCHEM    NG-06     10/08/86  NG-06G         HIT       NO HIT
EVCHEM    NG-10     10/03/86  NG-10G         NO HIT    NO HIT
EVCHEM    NG-12     10/15/86  NG-12G         NO HIT
EVCHEM    NG-13     10/15/86  NG-13G         NO HIT
EVCHEM    NG-14     10/15/86  NG-14G         NO HIT
EVCHEM    NG-15     10/15/86  NG-15G         NO HIT
EVCHEM    OG-03     10/09/86  OG-03G         HIT
EVCHEM    PS-02     10/13/86  PS-02G         NO HIT    NO HIT
EVCHEM    PS-03     10/13/86  PS-03G         NO HIT    NO HIT
EVCHEM    PS-04     10/10/86  PS-04G         NO HIT    NO HIT
EVCHEM    SD-01     10/09/86  SD-01G         NO HIT    HIT
EVCHEM    SD-02     10/07/86  SD-02G               c   NO HIT
EVCHEM    SR-01     10/06/86  SR-01G         NO HIT
EVCHEM    SR-02     10/06/86  SR-02G         NO HIT
EVCHEM    SR-04     10/06/86  SR-04G         NO HIT
EVCHEM    SR-07     10/03/86  SR-07G               c   HIT
```

| | | | | | |
|---|---|---|---|---|---|
| EVCHEM | SR-08 | 10/03/86 | SR-08G | NO HIT | HIT |
| EVCHEM | SS-01 | 10/06/86 | SS-01G | NO HIT | |
| EVCHEM | SS-03 | 10/06/86 | SS-03G | NO HIT | |

*Amphipod toxicity and benthic infauna abundance were the only biological effects tested in the EVCHEM survey.

| | | | | | |
|---|---|---|---|---|---|
| EVERETT1 | EV-20 | 01/01/85 | EV-20 | NO HIT | |
| EVERETT1 | EV-21 | 01/01/85 | EV-21 | NO HIT | |
| EVERETT1 | EV-22 | 01/01/85 | EV-22 | NO HIT | |
| EVERETT1 | EV-23 | 01/01/85 | EV-23 | NO HIT | |
| EVERETT1 | EV-24 | 01/01/85 | EV-24 | HIT | |
| EVERETT1 | EV-25 | 01/01/85 | EV-25 | NO HIT | |

*Amphipod toxicity was the only biological effect tested in the EVERETT1 survey.

| | | | | | |
|---|---|---|---|---|---|
| TPPS3AB | EB-33 | 03/15/82 | 1779 | | HIT |
| TPPS3AB | EB-33 | 07/15/82 | 2080 | | HIT |
| TPPS3AB | EB-35 | 03/15/82 | 1775 | | HIT |
| TPPS3AB | EB-35 | 07/15/82 | 2079 | | HIT |
| TPPS3AB | EB-36 | 03/15/82 | 1776 | | HIT |
| TPPS3AB | EB-36 | 07/15/82 | 2072 | | HIT |
| TPPS3AB | EB-38 | 03/15/82 | 1778 | | HIT |
| TPPS3AB | EB-38 | 07/15/82 | 2074 | | HIT |
| TPPS3AB | WP-01 | 07/15/82 | 2088 | | NO HIT |
| TPPS3AB | WP-02 | 07/15/82 | 2089 | | NO HIT |
| TPPS3AB | WP-03 | 07/15/82 | 2090 | | HIT |
| TPPS3AB | WP-04 | 07/15/82 | 2091 | | NO HIT |
| TPPS3AB | WP-05 | 07/15/82 | 2092 | | NO HIT |
| TPPS3AB | WP-06 | 07/15/82 | 2084 | | NO HIT |
| TPPS3AB | WP-07 | 07/15/82 | 2093 | | NO HIT |
| TPPS3AB | WP-08 | 07/15/82 | 2083 | | HIT |
| TPPS3AB | WP-09 | 07/15/82 | 2082 | | NO HIT |
| TPPS3AB | WP-10 | 07/15/82 | 2076 | | NO HIT |
| TPPS3AB | WP-11 | 03/15/82 | 1789 | | b |
| TPPS3AB | WP-12 | 03/15/82 | 1786 | | NO HIT |
| TPPS3AB | WP-12 | 07/15/82 | 2069 | | NO HIT |
| TPPS3AB | WP-13 | 03/15/82 | 1784 | | NO HIT |
| TPPS3AB | WP-13 | 07/15/82 | 2070 | | NO HIT |
| TPPS3AB | WP-14 | 03/15/82 | 1785 | | NO HIT |
| TPPS3AB | WP-14 | 07/15/82 | 2085 | | b |
| TPPS3AB | WP-15 | 03/15/82 | 1817 | | NO HIT |
| TPPS3AB | WP-15 | 07/15/82 | 2094 | | NO HIT |
| TPPS3AB | WP-16 | 03/15/82 | 1816 | | HIT |
| TPPS3AB | WP-16 | 07/15/82 | 2086 | | NO HIT[a] |

*Benthic infauna abundance was the only biological effect tested in the TPPS3AB survey.

---

[a] Although the indicated biological effect was statistically significant ($P \leq 0.05$) it is not classified as a "hit" because mortality was <25% for AMPT or abundance depression was <50% for BENA.

[b] The indicated biological effect was excluded because of a chemical anomaly.

[c] The indicated biological effect was excluded as inconclusive because of inadequate statistical power.

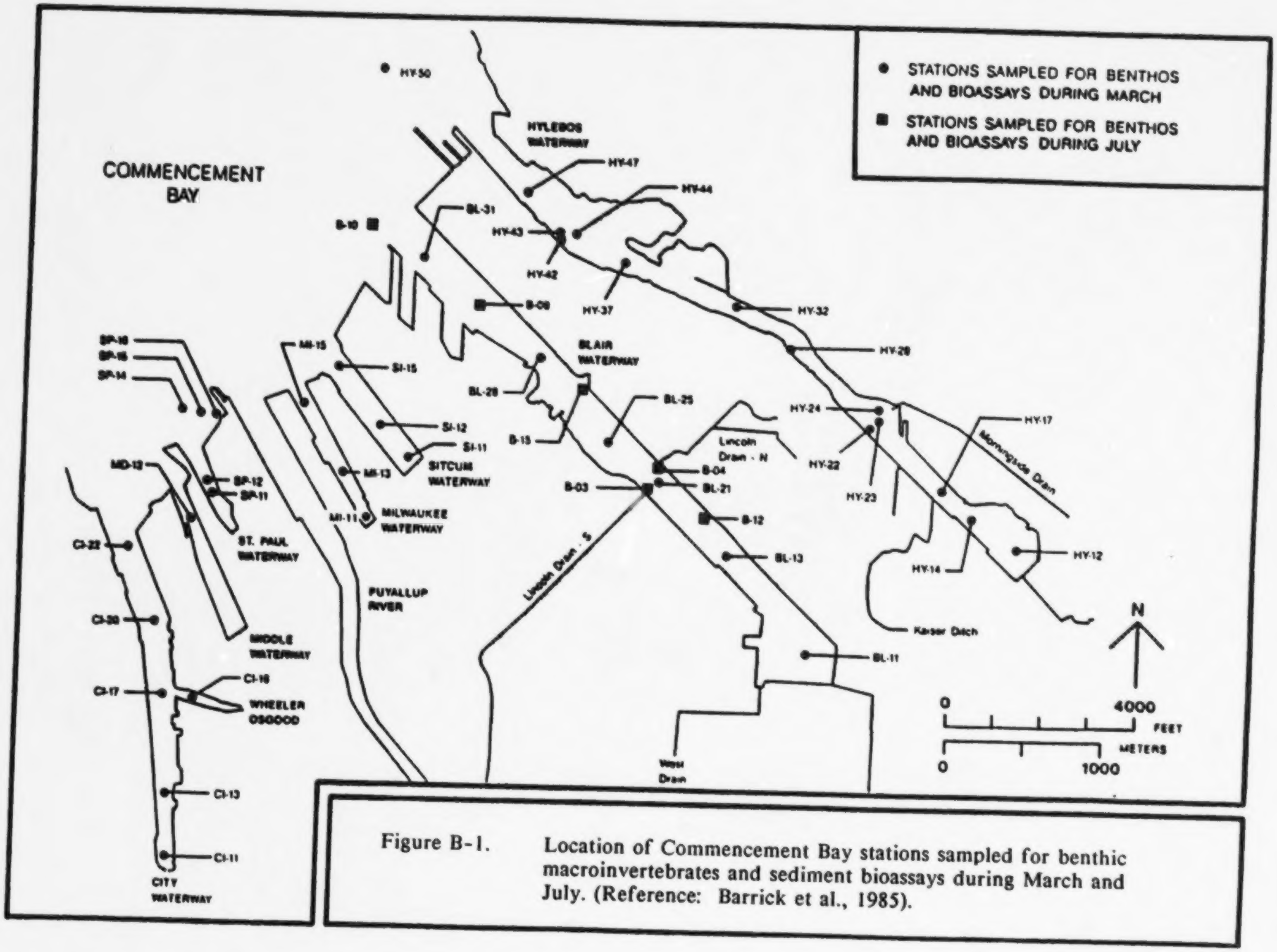

STATIONS SAMPLED FOR BENTHOS AND BIOASSAYS DURING MARCH
STATIONS SAMPLED FOR BENTHOS AND BIOASSAYS DURING JULY
COMMENCEMENT BAY
HY-50
HYLEBOS WATERWAY
HY-47
HY-44
HY-43
HY-42
HY-37
HY-32
HY-28
HY-24
HY-22
HY-23
HY-17
HY-14
HY-12
Morningside Drain
Kaiser Ditch
BL-31
B-10
B-09
BLAIR WATERWAY
BL-28
B-15
BL-25
Lincoln Drain - N
B-04
BL-21
B-03
B-12
BL-13
BL-11
Lincoln Drain - S
West Drain
SP-16
SP-15
SP-14
SP-12
SP-11
ST. PAUL WATERWAY
MD-12
MIDDLE WATERWAY
MI-15
MI-13
MI-11
MILWAUKEE WATERWAY
SI-15
SI-12
SI-11
SITCUM WATERWAY
PUYALLUP RIVER
CI-22
CI-20
CI-17
CI-16
WHEELER OSGOOD
CI-13
CI-11
CITY WATERWAY
N
0
4000
FEET
METERS
0
1000

Figure B-1. Location of Commencement Bay stations sampled for benthic macroinvertebrates and sediment bioassays during March and July. (Reference: Barrick et al., 1985).

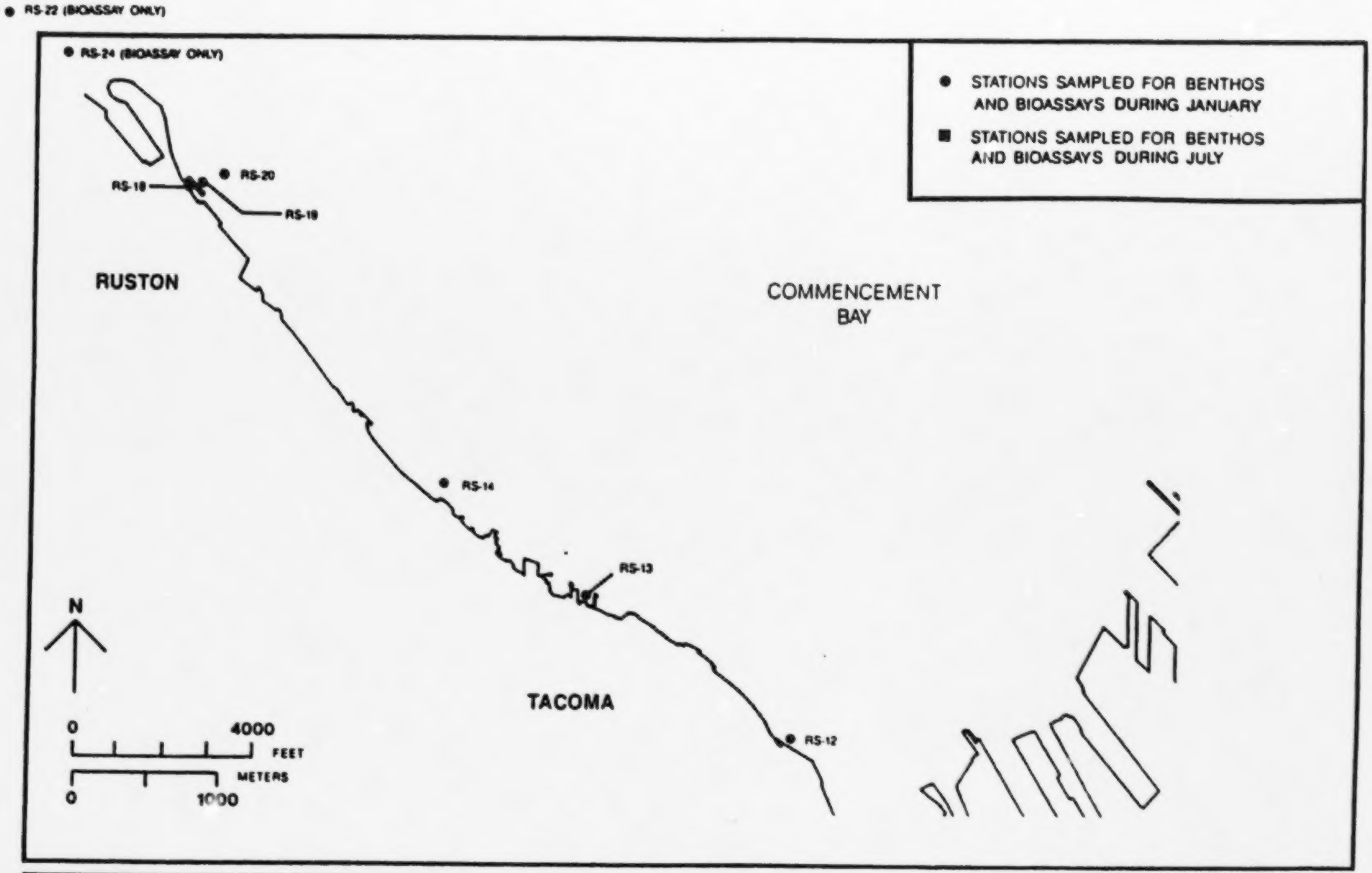

RS-22 (BIOASSAY ONLY)
RS-24 (BIOASSAY ONLY)
● STATIONS SAMPLED FOR BENTHOS AND BIOASSAYS DURING JANUARY
■ STATIONS SAMPLED FOR BENTHOS AND BIOASSAYS DURING JULY
RS-20
RS-18
RS-19
RUSTON
COMMENCEMENT BAY
RS-14
RS-13
N
TACOMA
RS-12
0
4000
FEET
METERS
0
1000

Figure B-1. (Continued).

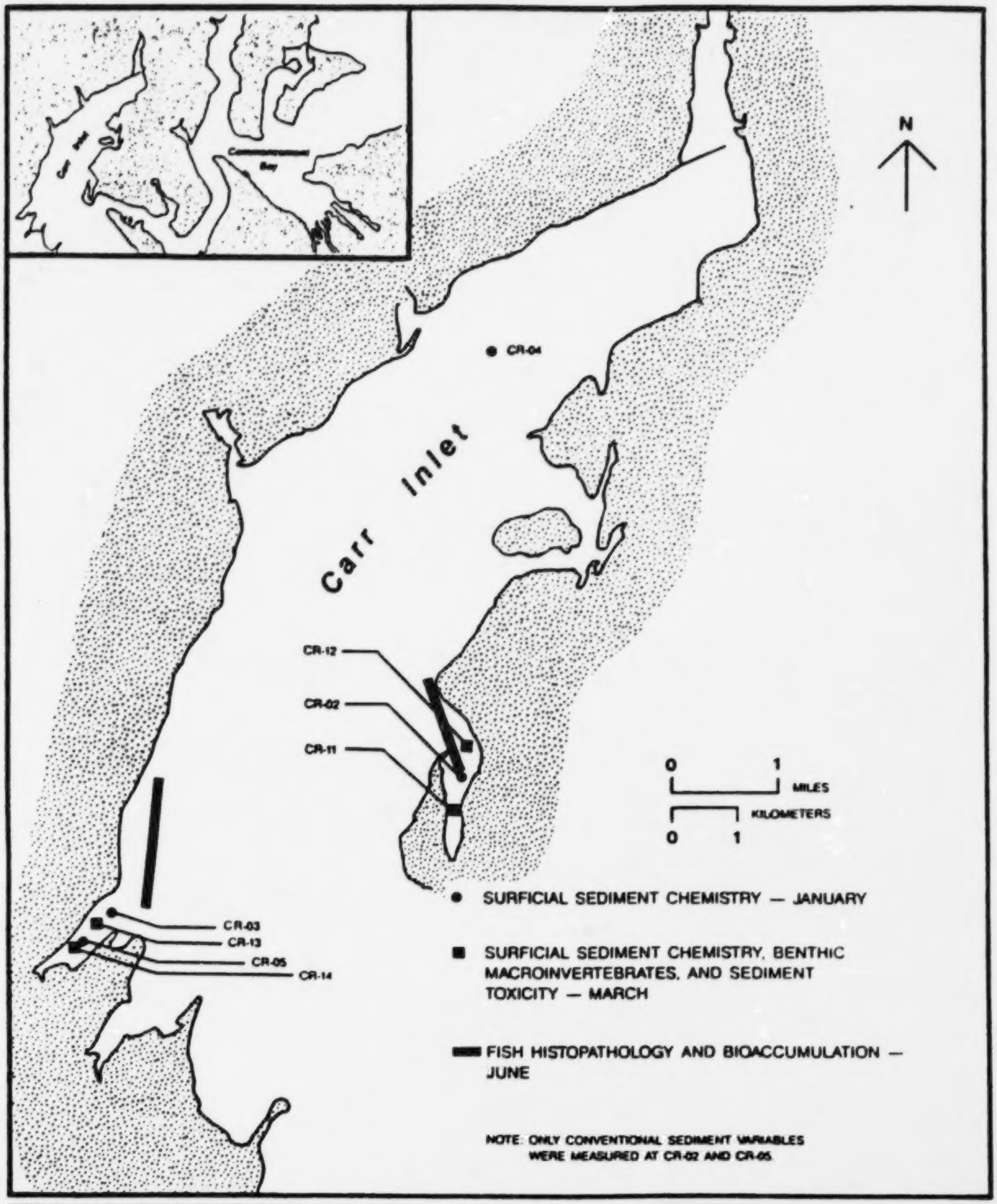

Commencement Bay
N
CR-04
Carr Inlet
CR-12
CR-02
CR-11
0 1 MILES
KILOMETERS 0 1
CR-03
CR-13
CR-05
CR-14
● SURFICIAL SEDIMENT CHEMISTRY — JANUARY
■ SURFICIAL SEDIMENT CHEMISTRY, BENTHIC MACROINVERTEBRATES, AND SEDIMENT TOXICITY — MARCH
▬ FISH HISTOPATHOLOGY AND BIOACCUMULATION — JUNE
NOTE: ONLY CONVENTIONAL SEDIMENT VARIABLES WERE MEASURED AT CR-02 AND CR-05.

Figure B-2. Locations of reference stations sampled in Carr Inlet. (Reference: Barrick et al. 1985).

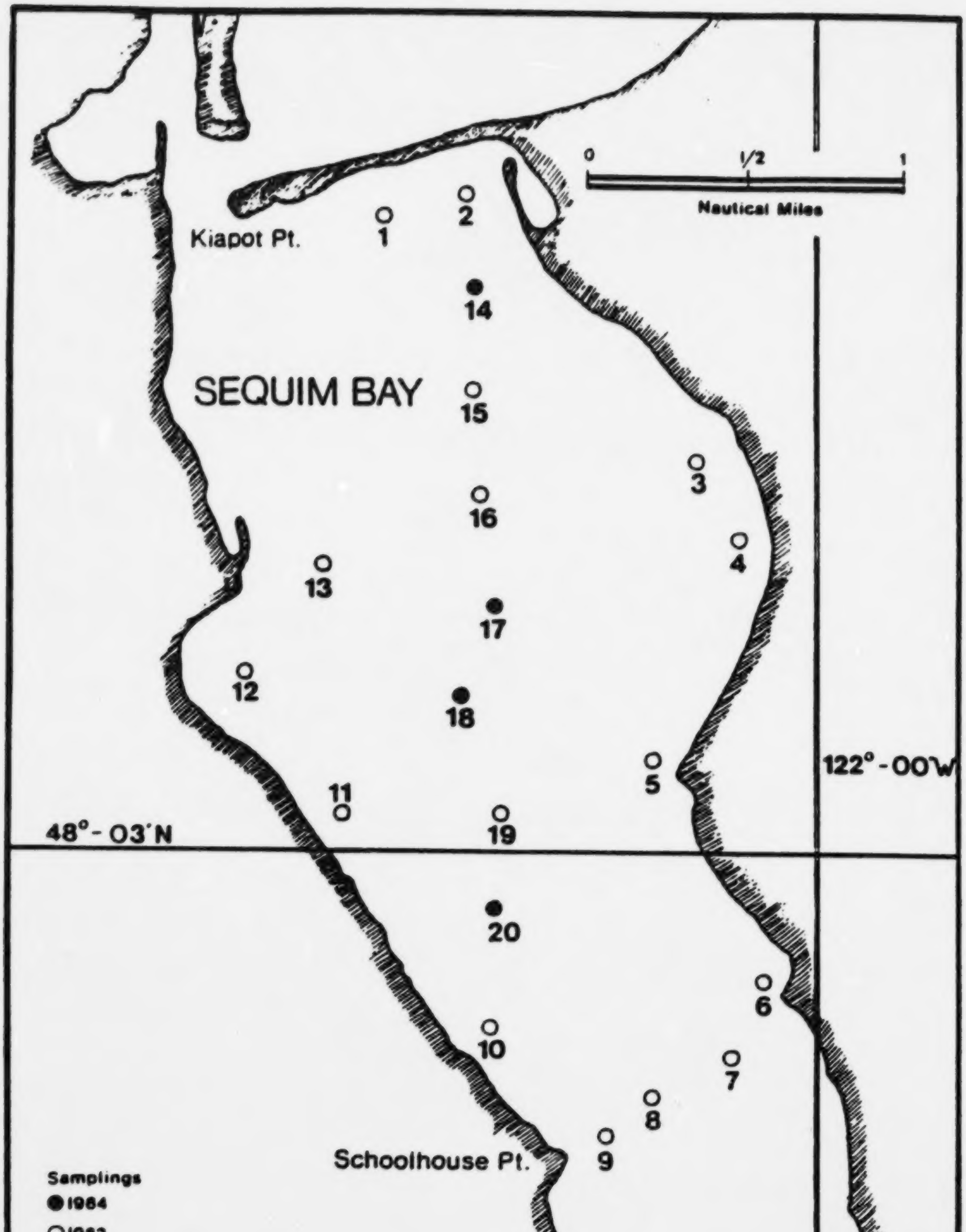

0
1/2
1
Nautical Miles
Kiapot Pt.
1
2
14
SEQUIM BAY
15
3
16
4
13
17
12
18
5
122°-00'W
11
19
48°-03'N
20
6
10
7
8
9
Schoolhouse Pt.
Samplings
●1984
○1983

Figure B-3. Sequim Bay sampling stations. (Reference: Battelle 1985).

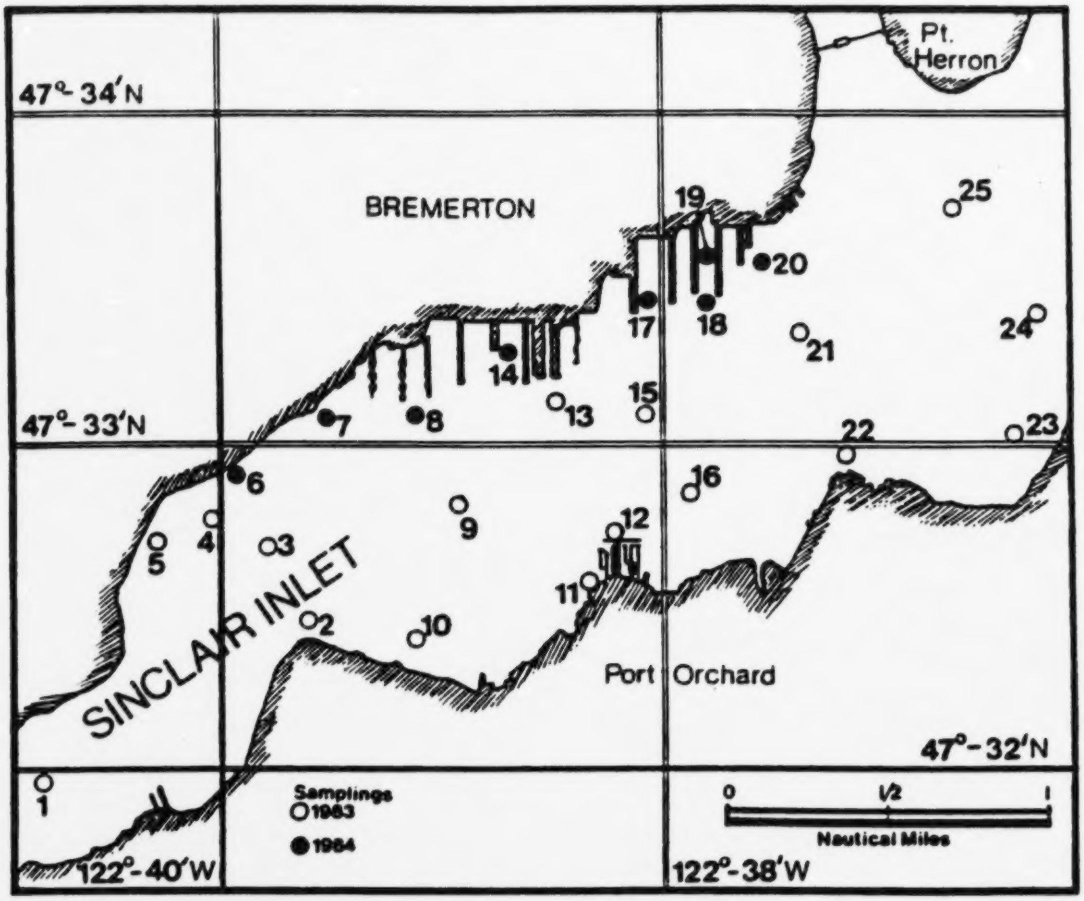

Pt. Herron
47°-34'N
BREMERTON
19
25
20
17
18
21
24
14
15
13
47°-33'N
7
8
22
23
6
16
9
12
5
4
3
SINCLAIR INLET
11
2
10
Port Orchard
47°-32'N
1
Samplings
○1983
●1984
0
1/2
1
Nautical Miles
122°-40'W
122°-38'W

Figure B-4. Sinclair Inlet sampling stations. (Reference: Battelle 1985).

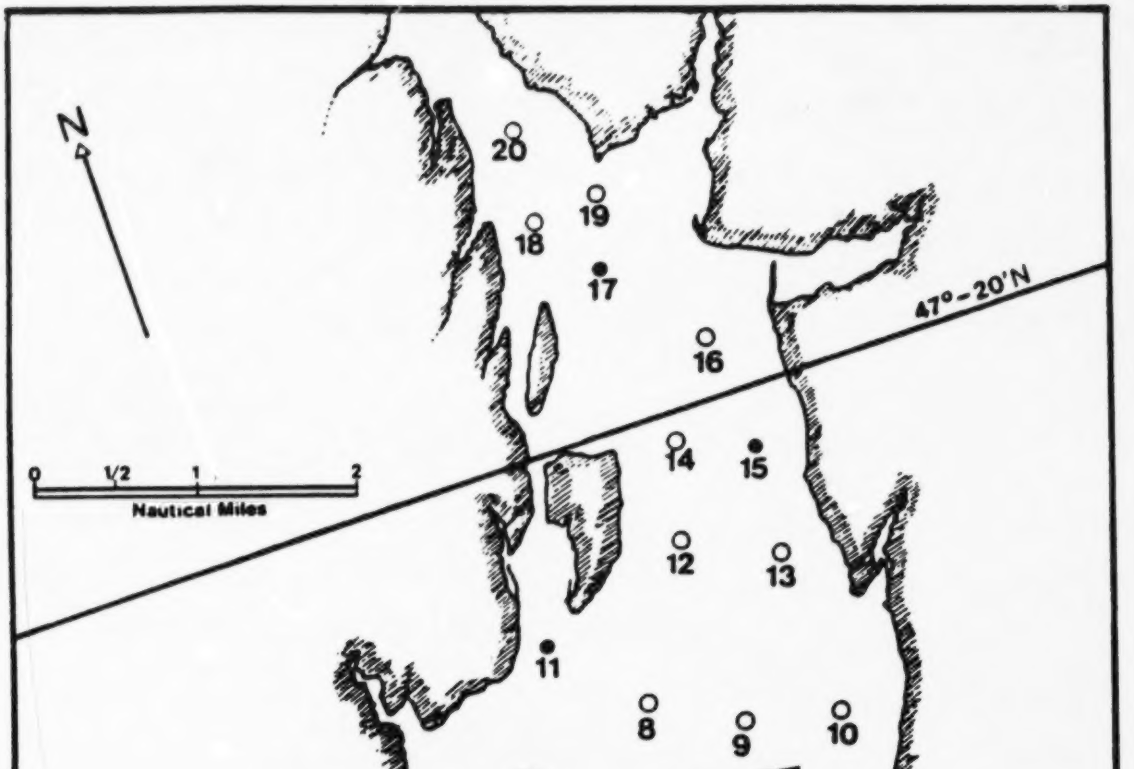

N
0
1/2
1
2
Nautical Miles
47°-20'N
20
19
18
17
16
14
15
12
13
11
8
9
10
CASE INLET
7
6
5
4
3
KEY PENINSULA
HARTSTENE ISLAND
2
Samplings
● 1984
○ 1983
1

Figure B-5. Case Inlet sampling stations. (Reference: Battelle 1985).

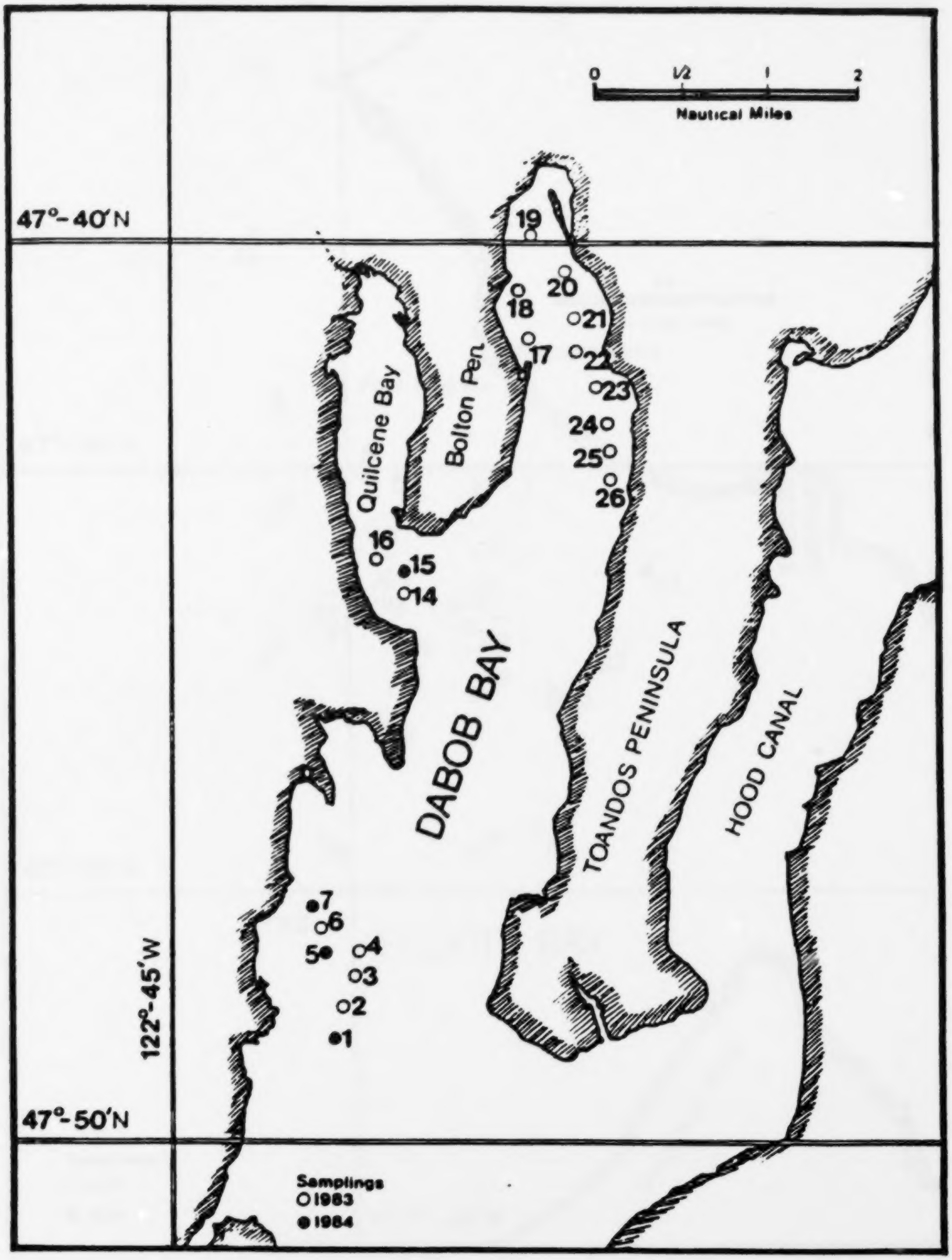

0
1/2
1
2
Nautical Miles
47°-40'N
47°-50'N
122°-45'W
Quilcene Bay
Bolton Pen.
DABOB BAY
TOANDOS PENINSULA
HOOD CANAL
1
2
3
4
5
6
7
14
15
16
17
18
19
20
21
22
23
24
25
26
Samplings
○1983
●1984

Figure B-6. Dabob Bay sampling stations. (Reference: Battelle 1985).

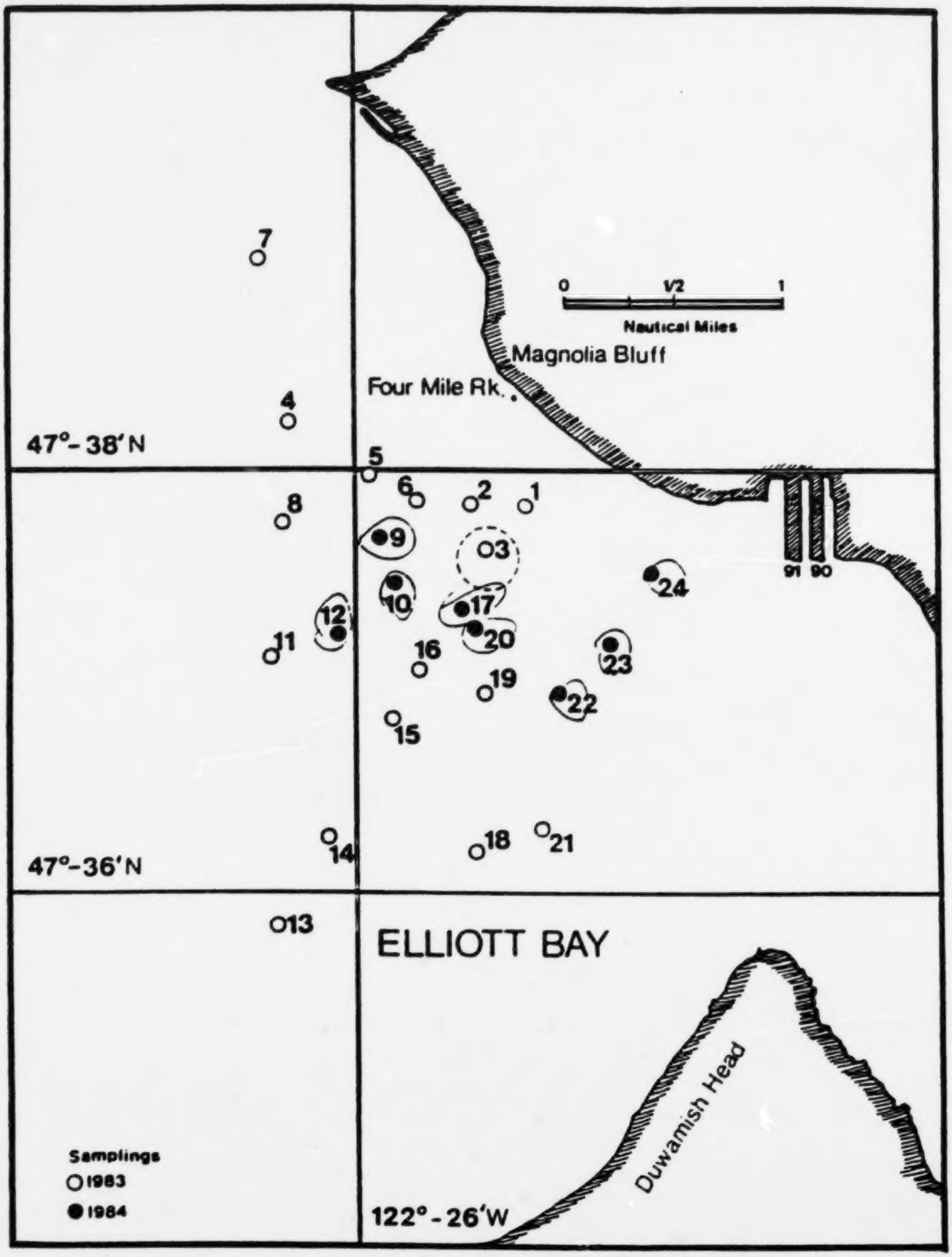

0
1/2
1
Nautical Miles
Magnolia Bluff
Four Mile Rk.
47°-38′N
47°-36′N
122°-26′W
ELLIOTT BAY
Duwamish Head
91
90
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Samplings
○1983
●1984

Figure B-7. Elliott Bay - Fourmile Rock sampling stations. (Reference: Battelle 1985).

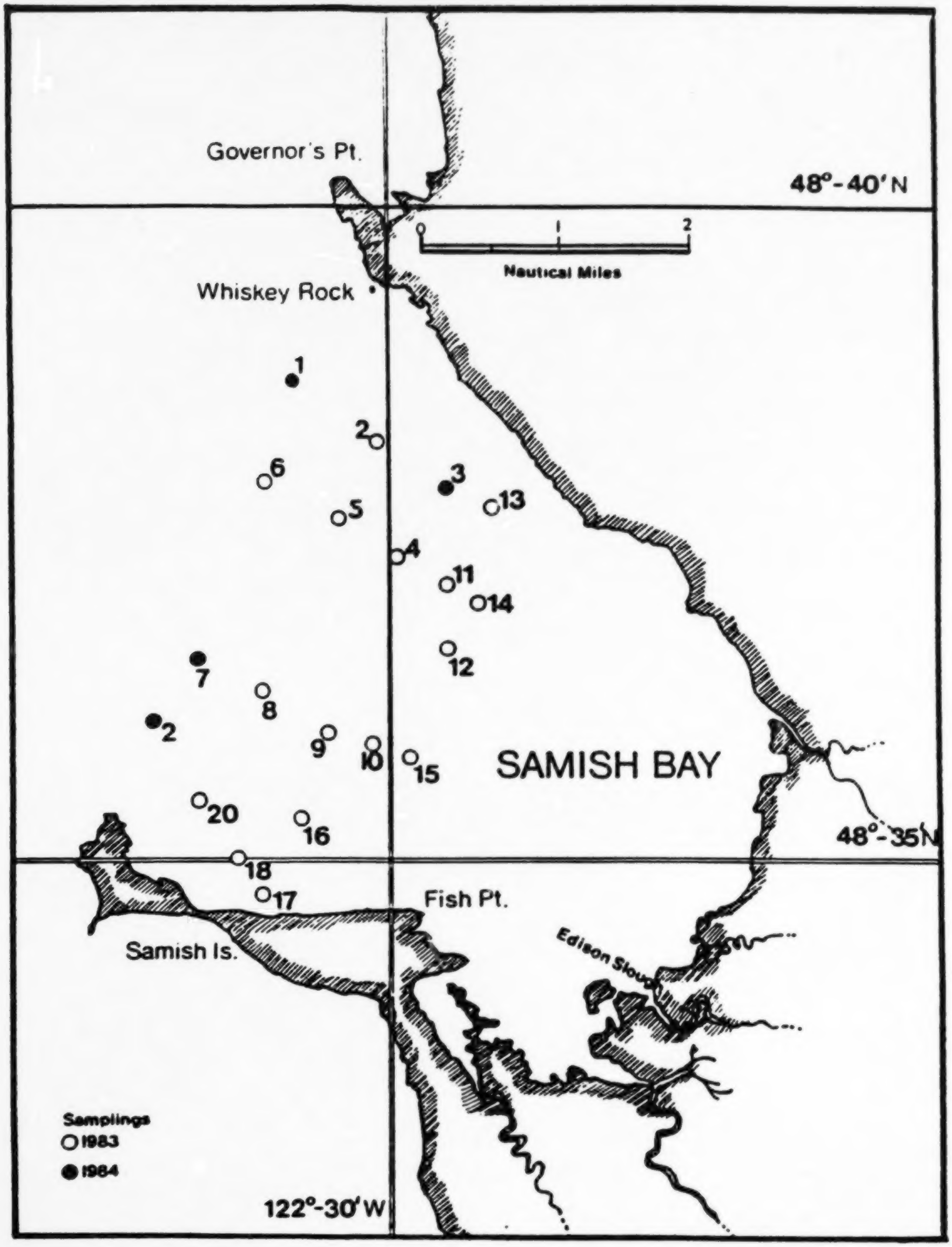

Governor's Pt.
48°-40'N
0 1 2
Nautical Miles
Whiskey Rock
1
2
6
3
13
5
4
11
14
12
7
8
2
9
10
15
SAMISH BAY
20
16
48°-35'N
18
17
Fish Pt.
Samish Is.
Edison Slough
Samplings
○ 1983
● 1984
122°-30'W

Figure B-8. Samish Bay sampling stations. (Reference: Battelle 1985).

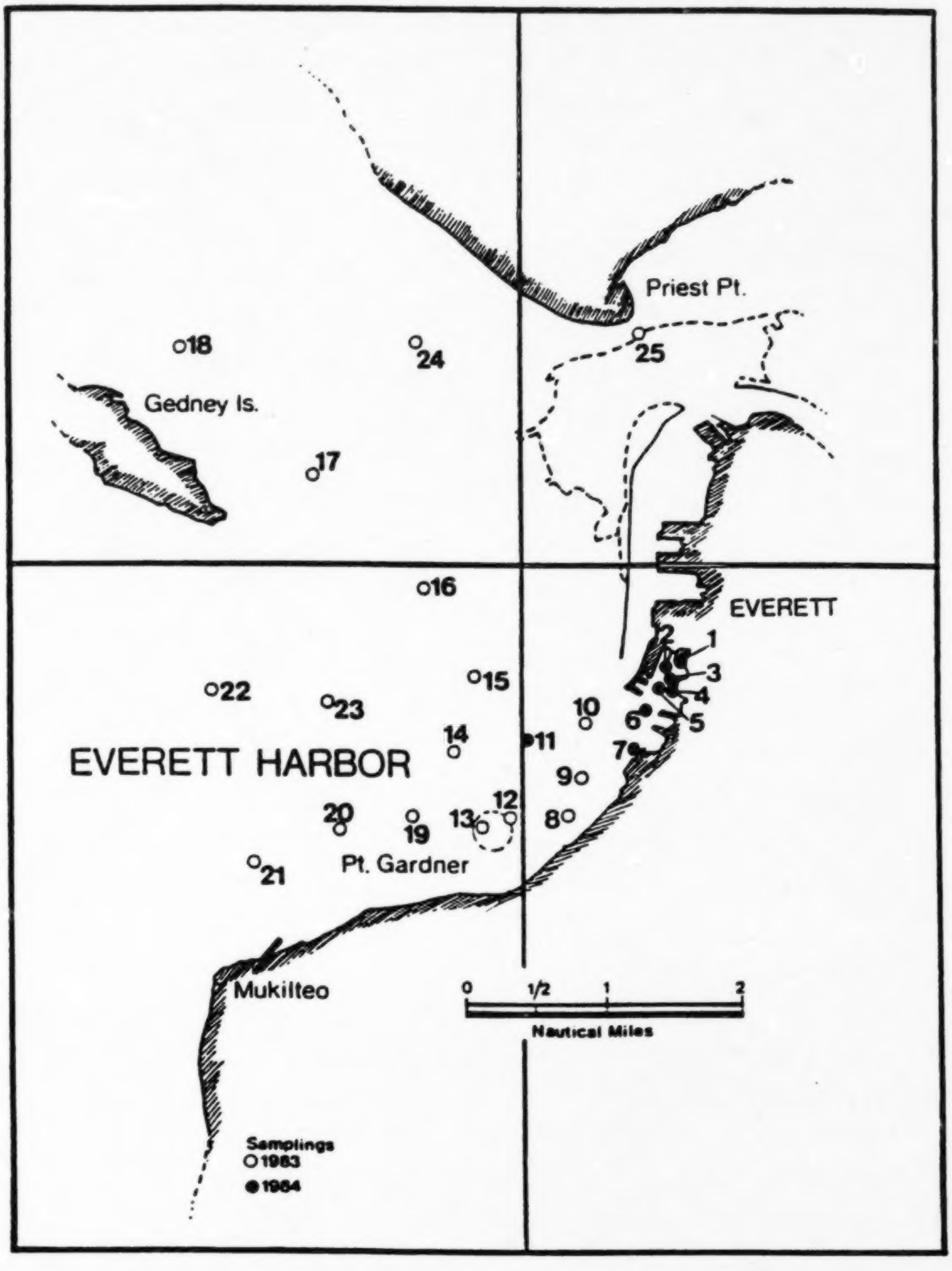

Priest Pt.
18
24
25
Gedney Is.
17
16
EVERETT
1
2
3
4
5
6
7
22
23
15
10
14
11
EVERETT HARBOR
9
20
19
13
12
8
21
Pt. Gardner
Mukilteo
0
1/2
1
2
Nautical Miles
Samplings
○ 1983
● 1984

Figure B-9. Everett Harbor - Port Gardner sampling stations. (Reference: Battelle 1985).

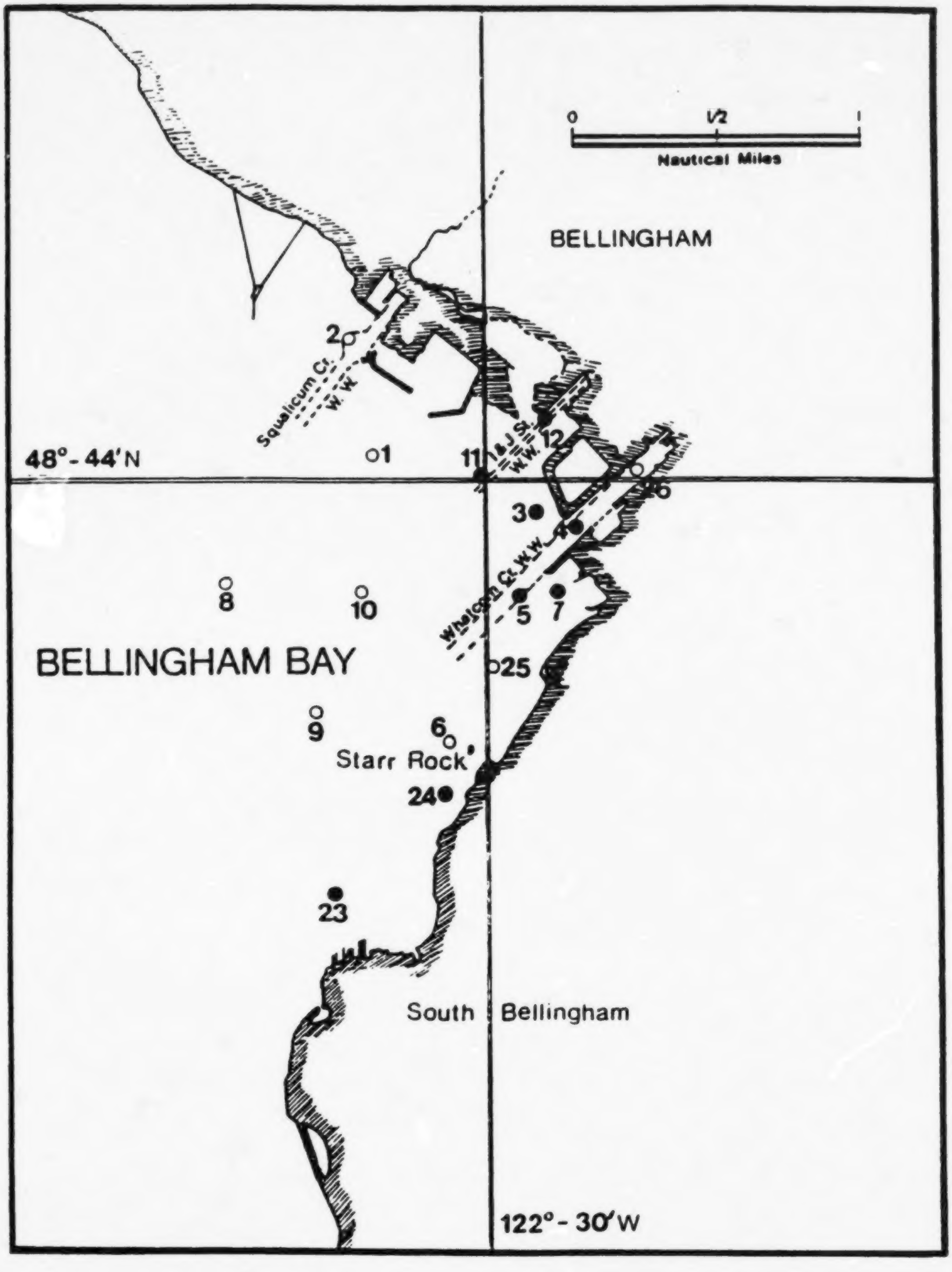

0
1/2
1
Nautical Miles
BELLINGHAM
2
Squalicum Cr. W.W.
1
11
I & J St. W.W.
12
48°-44'N
6
3
4
Whatcom Cr. W.W.
8
10
5
7
BELLINGHAM BAY
25
9
6
Starr Rock
24
23
South Bellingham
122°-30'W

Figure B-10. Bellingham Bay sampling stations (Inner Harbor). (Reference: Battelle 1985).

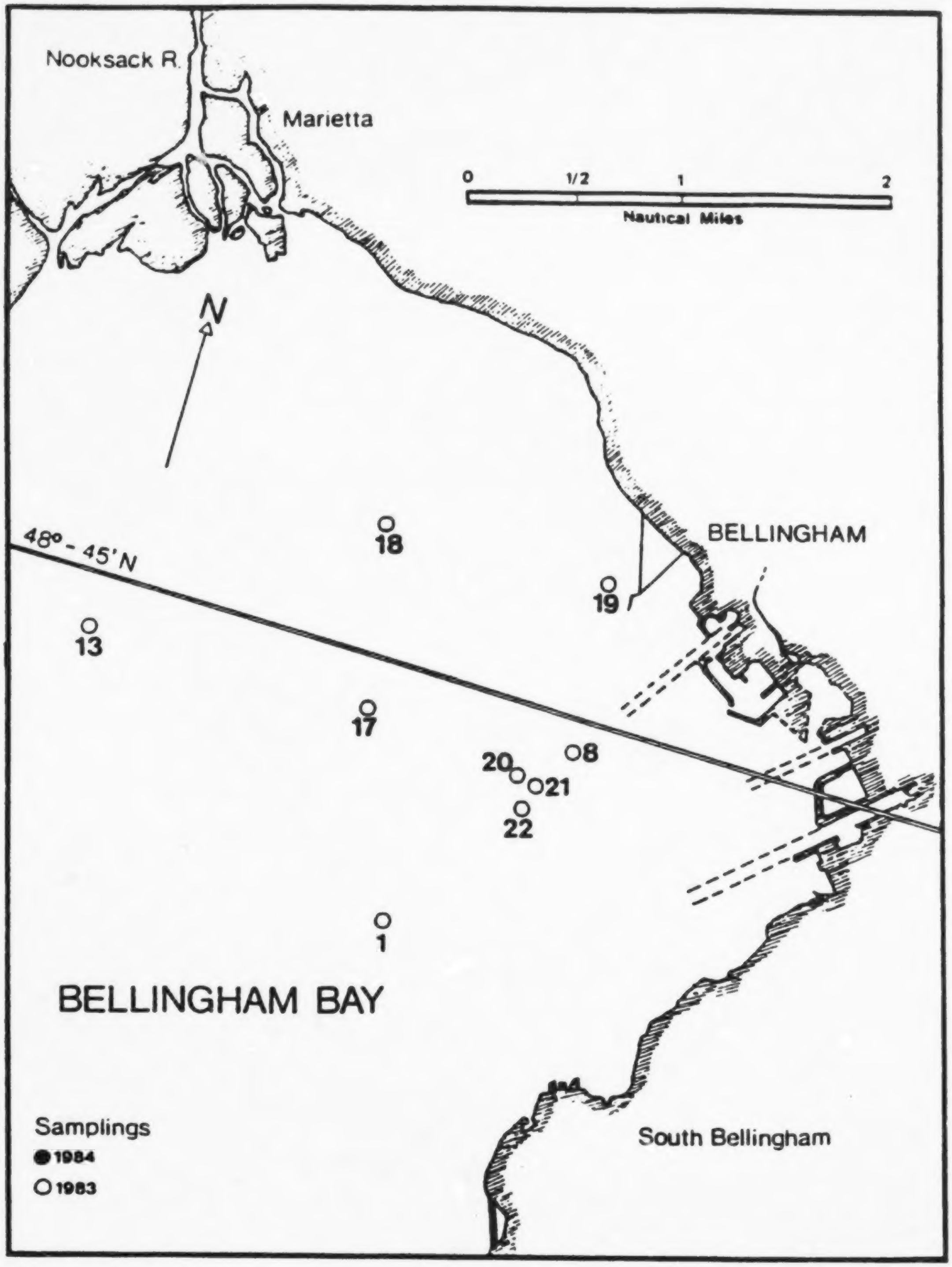

Nooksack R.
Marietta
0
1/2
1
2
Nautical Miles
N
18
48° - 45'N
BELLINGHAM
19
13
17
8
20
21
22
1
BELLINGHAM BAY
Samplings
● 1984
○ 1983
South Bellingham

Figure B-11. Bellingham Bay sampling stations (Outer Harbor). (Reference: Battelle 1985).

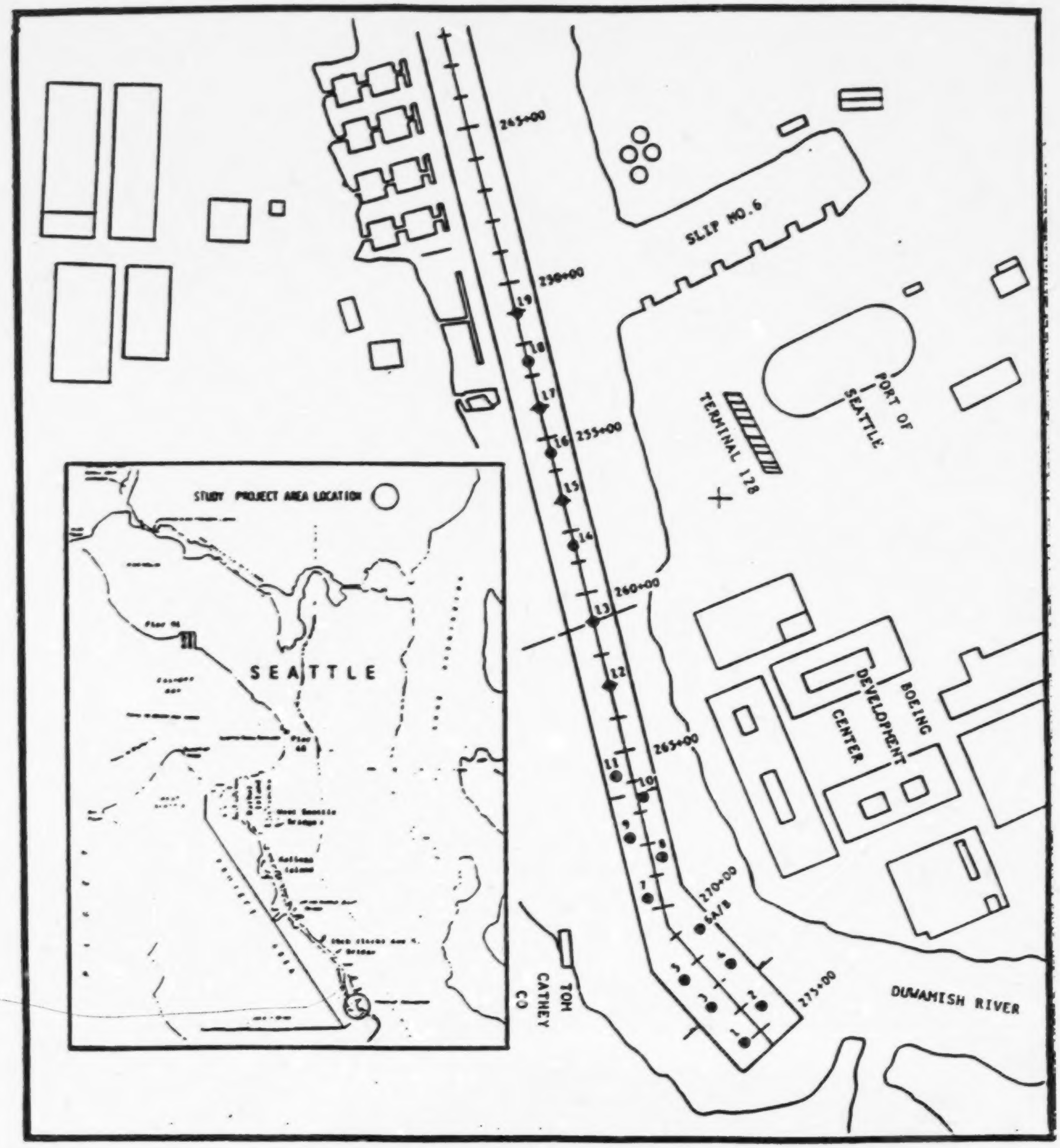

SLIP NO.6
PORT OF SEATTLE
TERMINAL 128
BOEING DEVELOPMENT CENTER
DUWAMISH RIVER
TOM CATHEY CO
STUDY PROJECT AREA LOCATION
SEATTLE
245+00
250+00
255+00
260+00
265+00
270+00
275+00
19
18
17
16
15
14
13
12
11
10
9
8
7
6A/B
5
4
3
2
1

Figure B-12. Sediment sampling station locations for dredged material characterization in Duwamish River. (Reference: Chan et al. 1985).

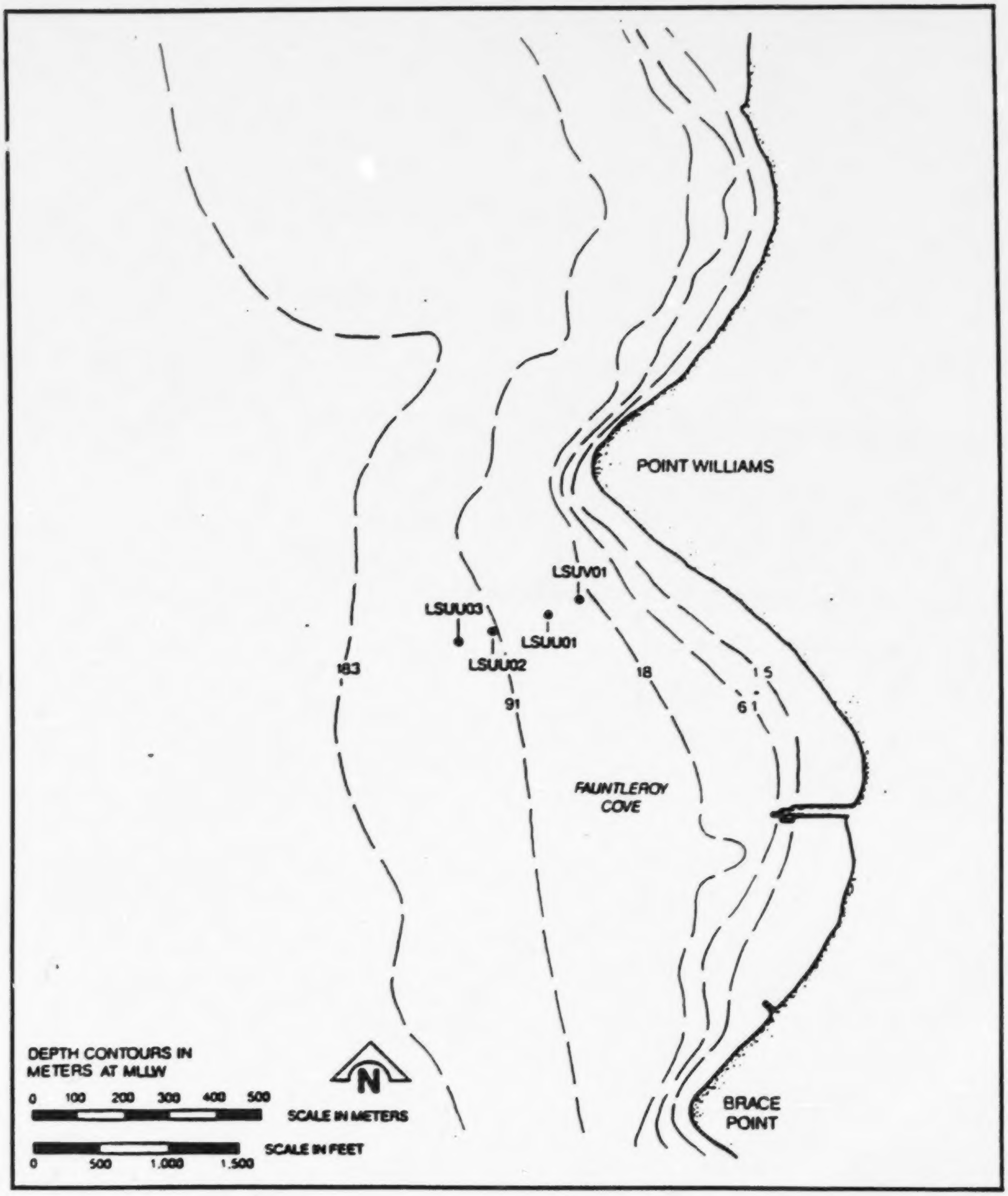

POINT WILLIAMS
LSUV01
LSUU03
LSUU01
LSUU02
183
18
5
6
91
FAUNTLEROY COVE
BRACE POINT
DEPTH CONTOURS IN METERS AT MLLW
N
0 100 200 300 400 500
SCALE IN METERS
SCALE IN FEET
0 500 1,000 1,500

Figure B-13. Point Williams benthos reference sampling station locations. (Reference: Osborn et al. 1985).

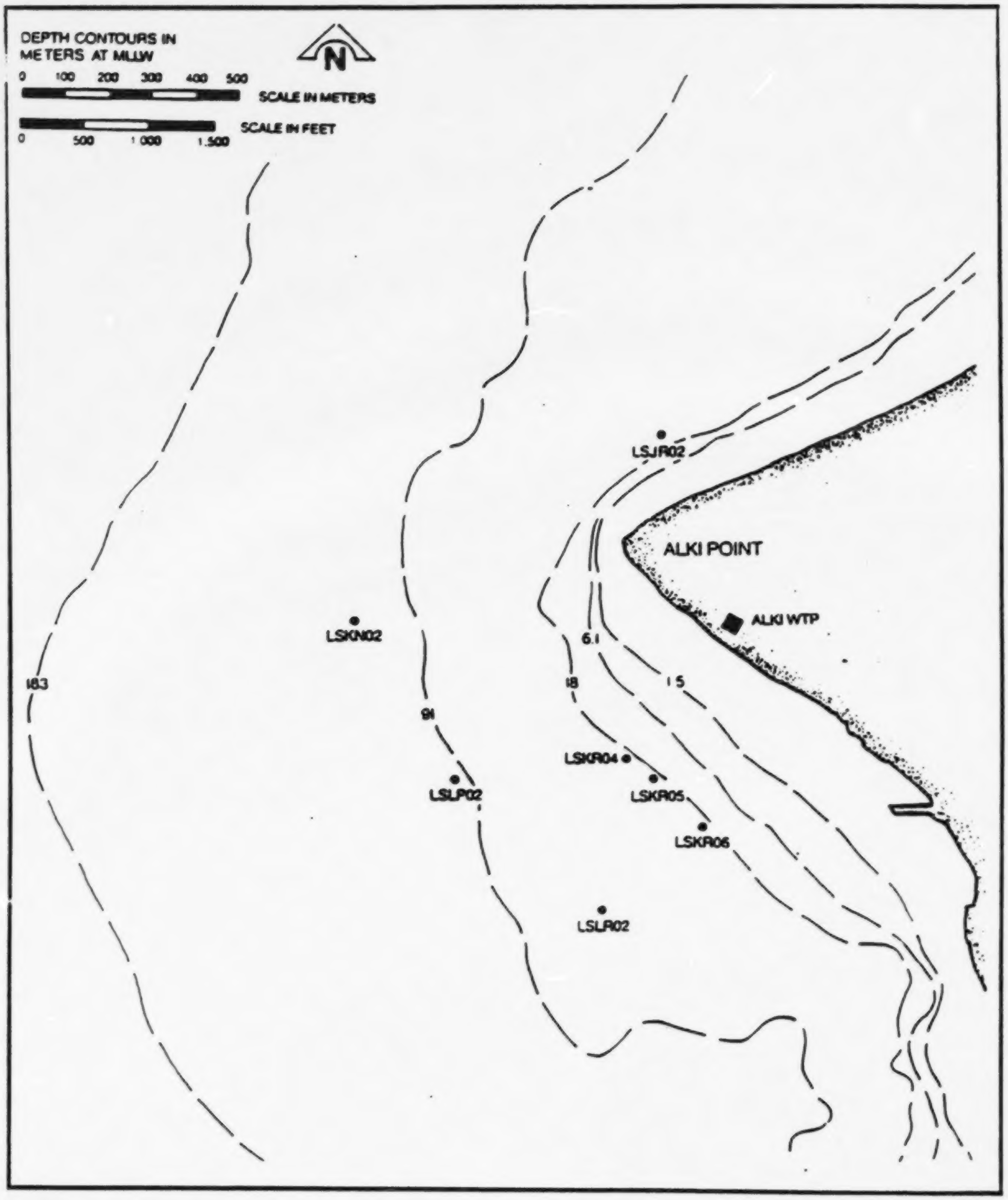

DEPTH CONTOURS IN
METERS AT MLLW
N
0 100 200 300 400 500
SCALE IN METERS
SCALE IN FEET
0 500 1 000 1 500
LSJR02
ALKI POINT
ALKI WTP
LSKN02
183
6.1
18
1.5
91
LSKR04
LSLP02
LSKR05
LSKR06
LSLR02

Figure B-14. Alki Point benthos sampling station locations. (Reference: Osborn et al. 1985).

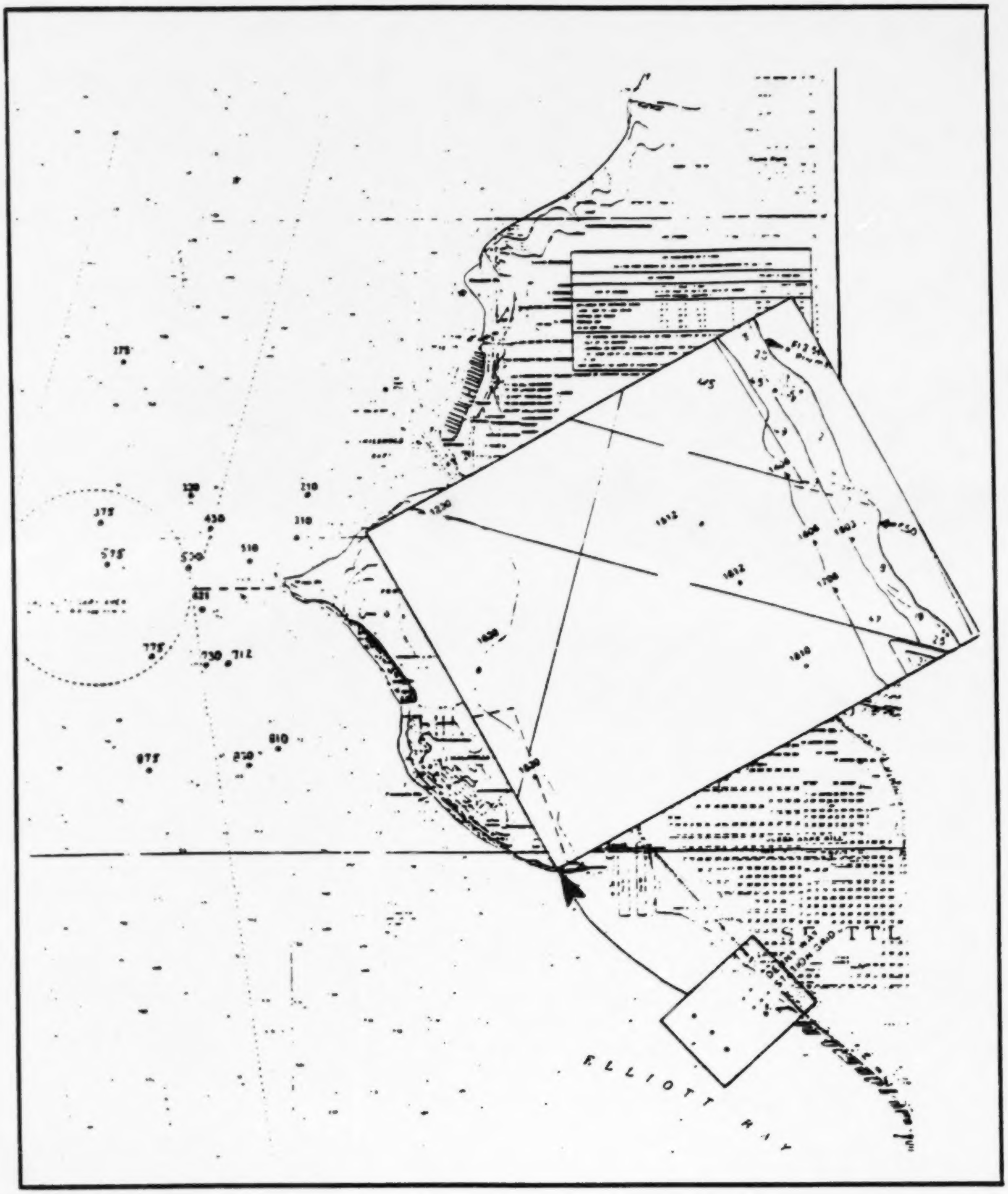
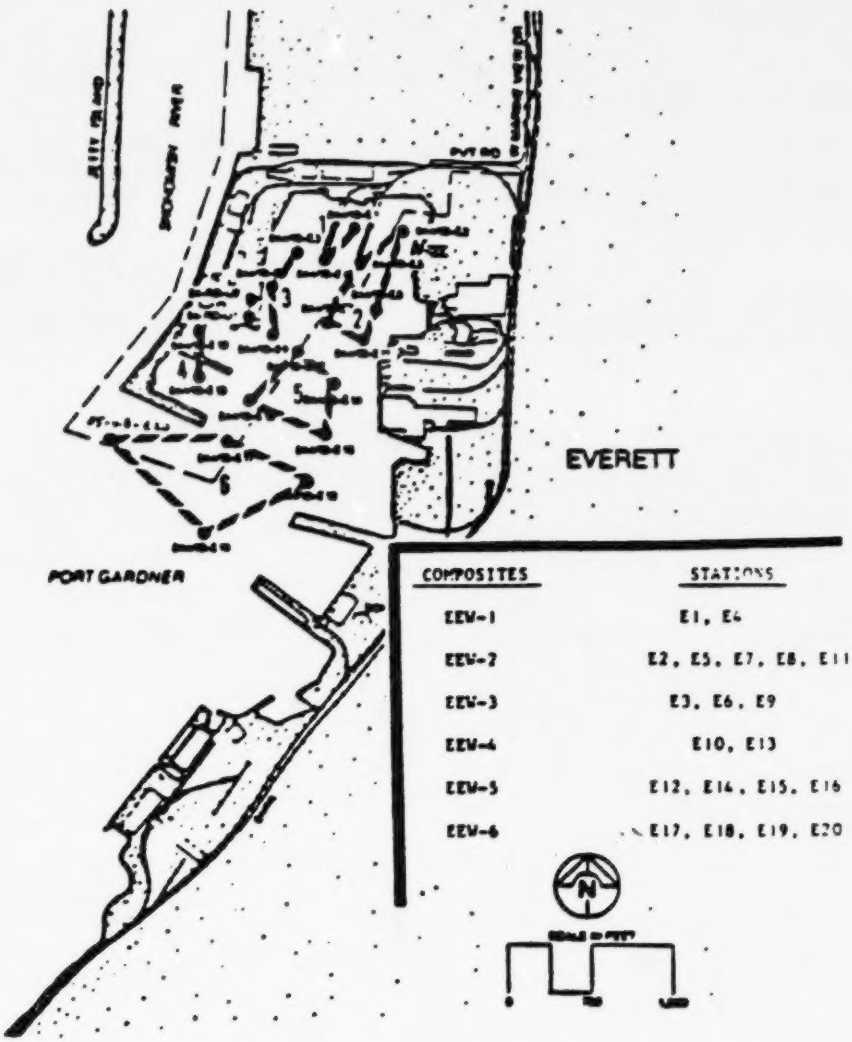


Figure B-15. Map showing the 26 stations in the central basin of Puget Sound and Elliott Bay sampled during Phase III of the TPPS program. (Reference: Romberg et al. 1984).


EVERETT
PORT GARDNER
JETTY ISLAND
SNOHOMISH RIVER
1
2
3
4
5
6
N

| COMPOSITES | STATIONS |
|---|---|
| EEW-1 | E1, E4 |
| EEW-2 | E2, E5, E7, E8, E11 |
| EEW-3 | E3, E6, E9 |
| EEW-4 | E10, E13 |
| EEW-5 | E12, E14, E15, E16 |
| EEW-6 | E17, E18, E19, E20 |

Figure B-16. Navy sediment sampling locations in the East Waterway of Everett. (Reference: U.S. Navy 1985).

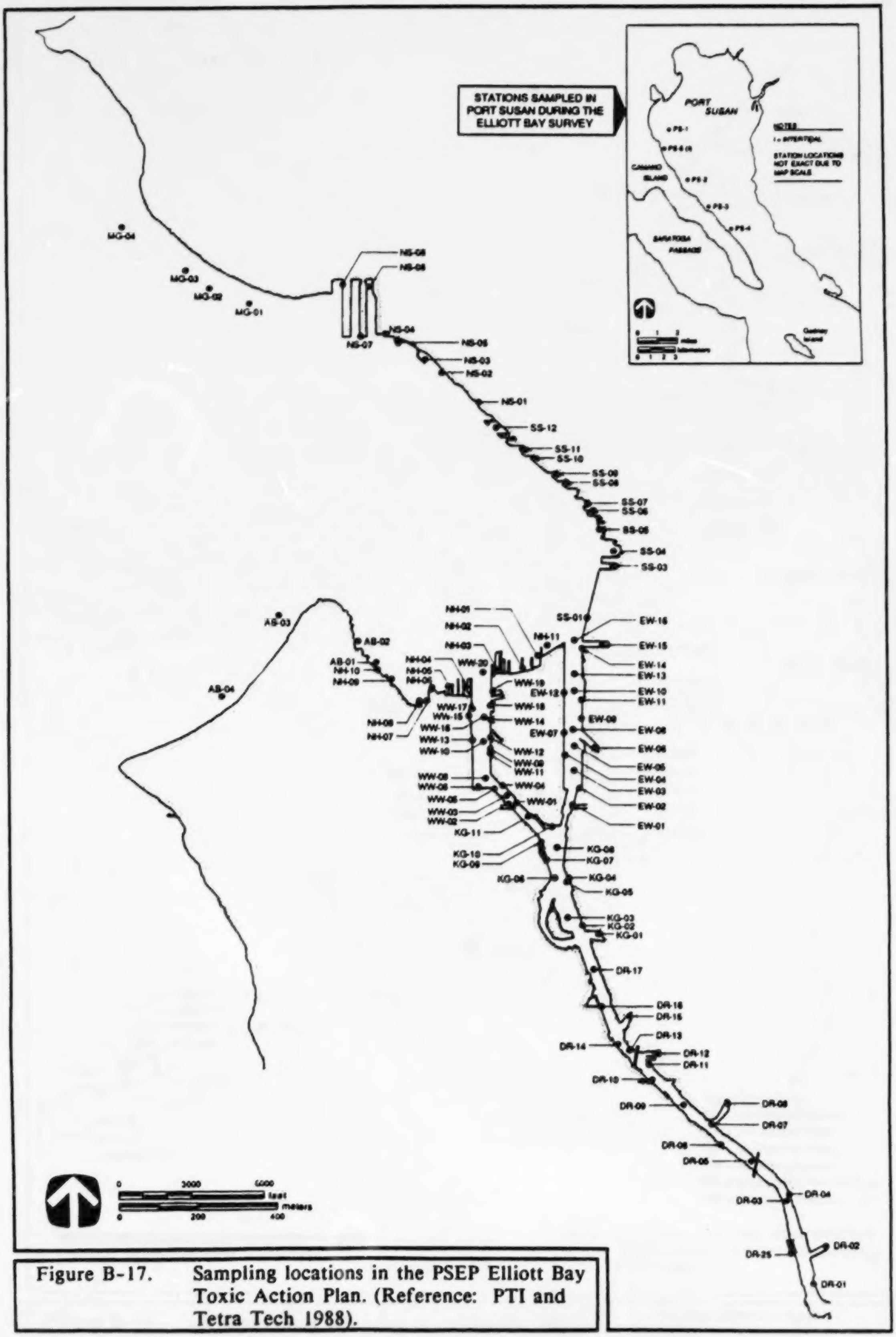

STATIONS SAMPLED IN PORT SUSAN DURING THE ELLIOTT BAY SURVEY
PORT SUSAN
PS-1
PS-5 (I)
CAMANO ISLAND
PS-2
PS-3
PS-4
SARATOGA PASSAGE
NOTES
I = INTERTIDAL
STATION LOCATIONS NOT EXACT DUE TO MAP SCALE
Gedney Island
0 1 2 miles
0 1 2 3 kilometers
MG-04
MG-03
MG-02
MG-01
NS-08
NS-06
NS-07
NS-04
NS-05
NS-03
NS-02
NS-01
SS-12
SS-11
SS-10
SS-09
SS-08
SS-07
SS-06
SS-05
SS-04
SS-03
SS-01
AB-03
AB-02
AB-01
AB-04
NH-01
NH-02
NH-03
NH-04
NH-05
NH-06
NH-07
NH-08
NH-09
NH-10
NH-11
WW-20
WW-19
WW-18
WW-17
WW-16
WW-15
WW-14
WW-13
WW-12
WW-11
WW-10
WW-09
WW-08
WW-06
WW-05
WW-04
WW-03
WW-02
WW-01
EW-16
EW-15
EW-14
EW-13
EW-12
EW-11
EW-10
EW-09
EW-08
EW-07
EW-06
EW-05
EW-04
EW-03
EW-02
EW-01
KG-11
KG-10
KG-09
KG-08
KG-07
KG-06
KG-05
KG-04
KG-03
KG-02
KG-01
DR-17
DR-16
DR-15
DR-14
DR-13
DR-12
DR-11
DR-10
DR-09
DR-08
DR-07
DR-06
DR-05
DR-04
DR-03
DR-25
DR-02
DR-01
0 3000 6000 feet
0 200 400 meters

Figure B-17. Sampling locations in the PSEP Elliott Bay Toxic Action Plan. (Reference: PTI and Tetra Tech 1988).

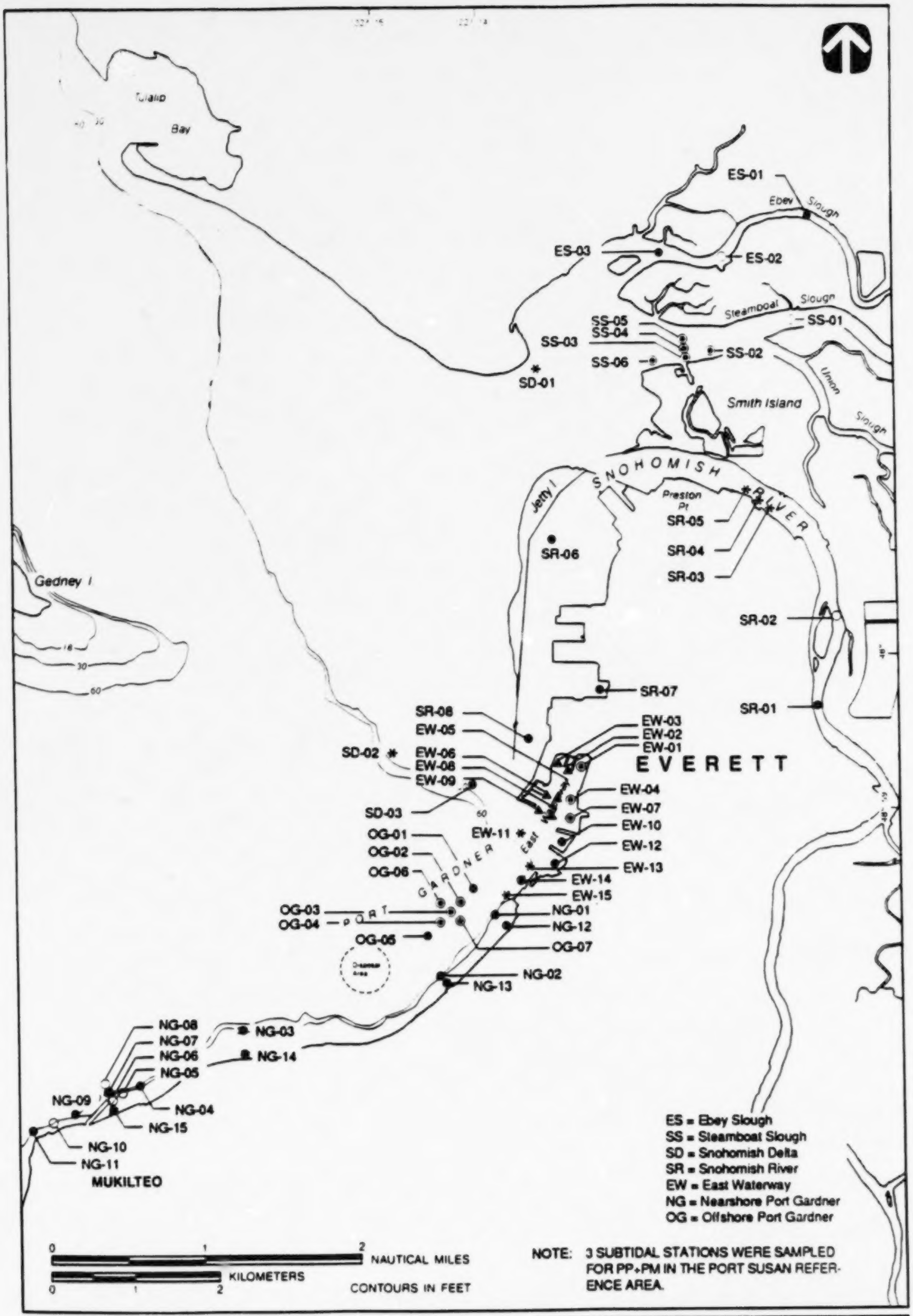

Tulalip
Bay
Gedney I
ES-01
Ebey Slough
ES-03
ES-02
Steamboat Slough
SS-05
SS-04
SS-03
SS-01
SS-06
SS-02
SD-01
Union Slough
Smith Island
SNOHOMISH RIVER
Jetty I
Preston Pt
SR-05
SR-04
SR-03
SR-06
SR-02
SR-07
SR-01
SR-08
EW-05
EW-03
EW-02
EW-01
SD-02
EW-06
EW-08
EW-09
EVERETT
EW-04
EW-07
SD-03
EW-10
EW-11
East Waterway
EW-12
OG-01
OG-02
OG-06
PORT GARDNER
EW-13
EW-14
EW-15
OG-03
OG-04
NG-01
NG-12
OG-05
OG-07
Disposal Area
NG-02
NG-13
NG-08
NG-07
NG-06
NG-05
NG-03
NG-14
NG-09
NG-04
NG-15
NG-10
NG-11
MUKILTEO
ES = Ebey Slough
SS = Steamboat Slough
SD = Snohomish Delta
SR = Snohomish River
EW = East Waterway
NG = Nearshore Port Gardner
OG = Offshore Port Gardner
0
1
2
NAUTICAL MILES
KILOMETERS
0
1
2
CONTOURS IN FEET
NOTE: 3 SUBTIDAL STATIONS WERE SAMPLED FOR PP+PM IN THE PORT SUSAN REFERENCE AREA.

Figure B-18. Approximate sampling locations for PSEP chemical studies in Everett Harbor. (Reference: PTI and Tetra Tech 1988).

○ PP (INCLUDES VOLATILES)
● PP - V
◉ PP + PM
✱ PP - V + PM
▲ V + PM

PP = Priority Pollutants
V = Volatile Compounds
PM = Pulpmill Compounds

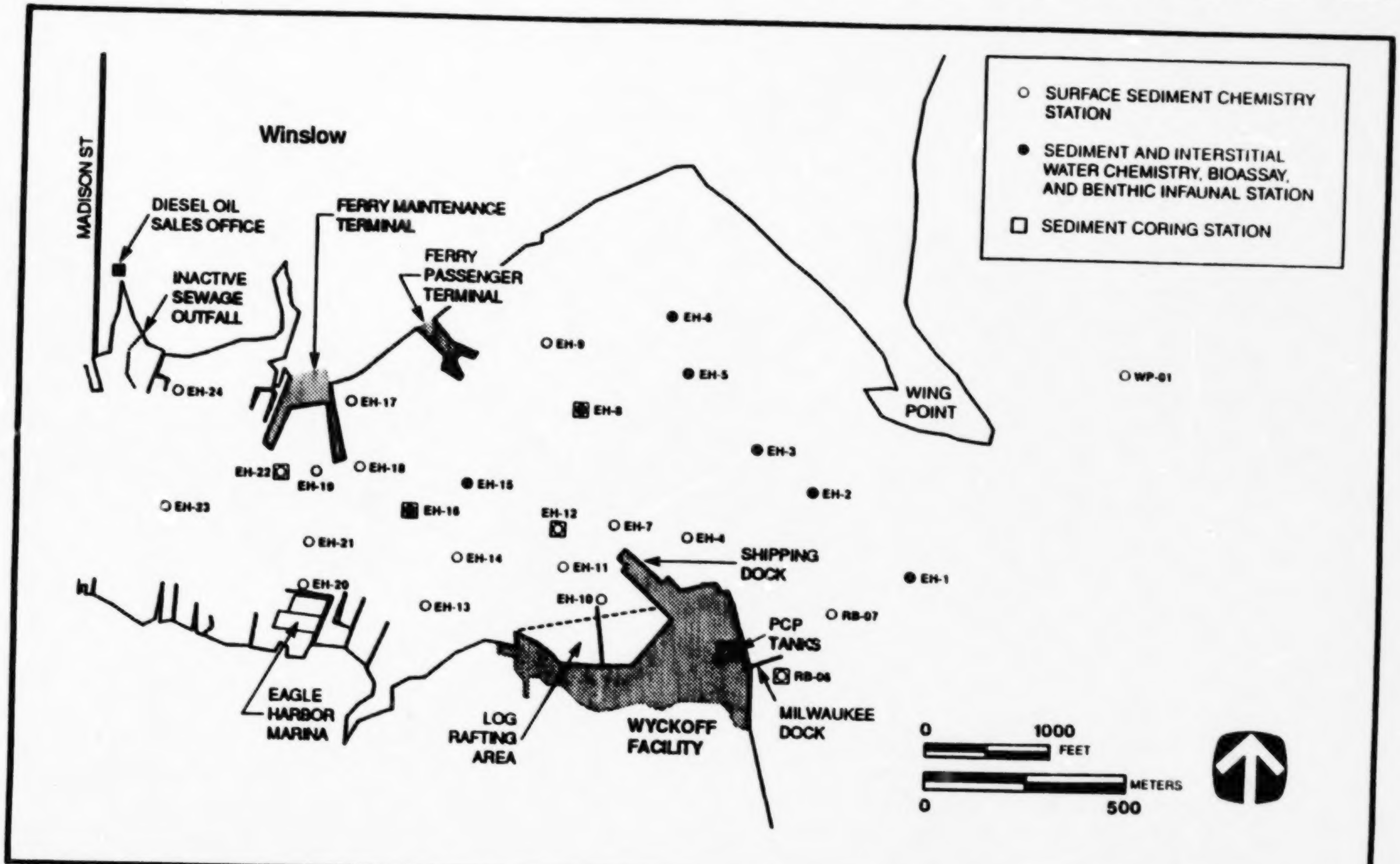

MADISON ST
Winslow
DIESEL OIL SALES OFFICE
INACTIVE SEWAGE OUTFALL
FERRY MAINTENANCE TERMINAL
FERRY PASSENGER TERMINAL
WING POINT
○ SURFACE SEDIMENT CHEMISTRY STATION
● SEDIMENT AND INTERSTITIAL WATER CHEMISTRY, BIOASSAY, AND BENTHIC INFAUNAL STATION
☐ SEDIMENT CORING STATION
EH-24
EH-17
EH-22
EH-19
EH-18
EH-23
EH-21
EH-20
EH-16
EH-15
EH-14
EH-13
EH-9
EH-8
EH-12
EH-11
EH-10
EH-7
EH-6
EH-5
EH-4
EH-3
EH-2
EH-1
WP-01
RB-07
RB-06
SHIPPING DOCK
PCP TANKS
MILWAUKEE DOCK
WYCKOFF FACILITY
LOG RAFTING AREA
EAGLE HARBOR MARINA
0
1000
FEET
METERS
0
500

Figure B-19. Sample station locations in Eagle Harbor Preliminary Investigation. (Reference: Barrick et al. 1986).

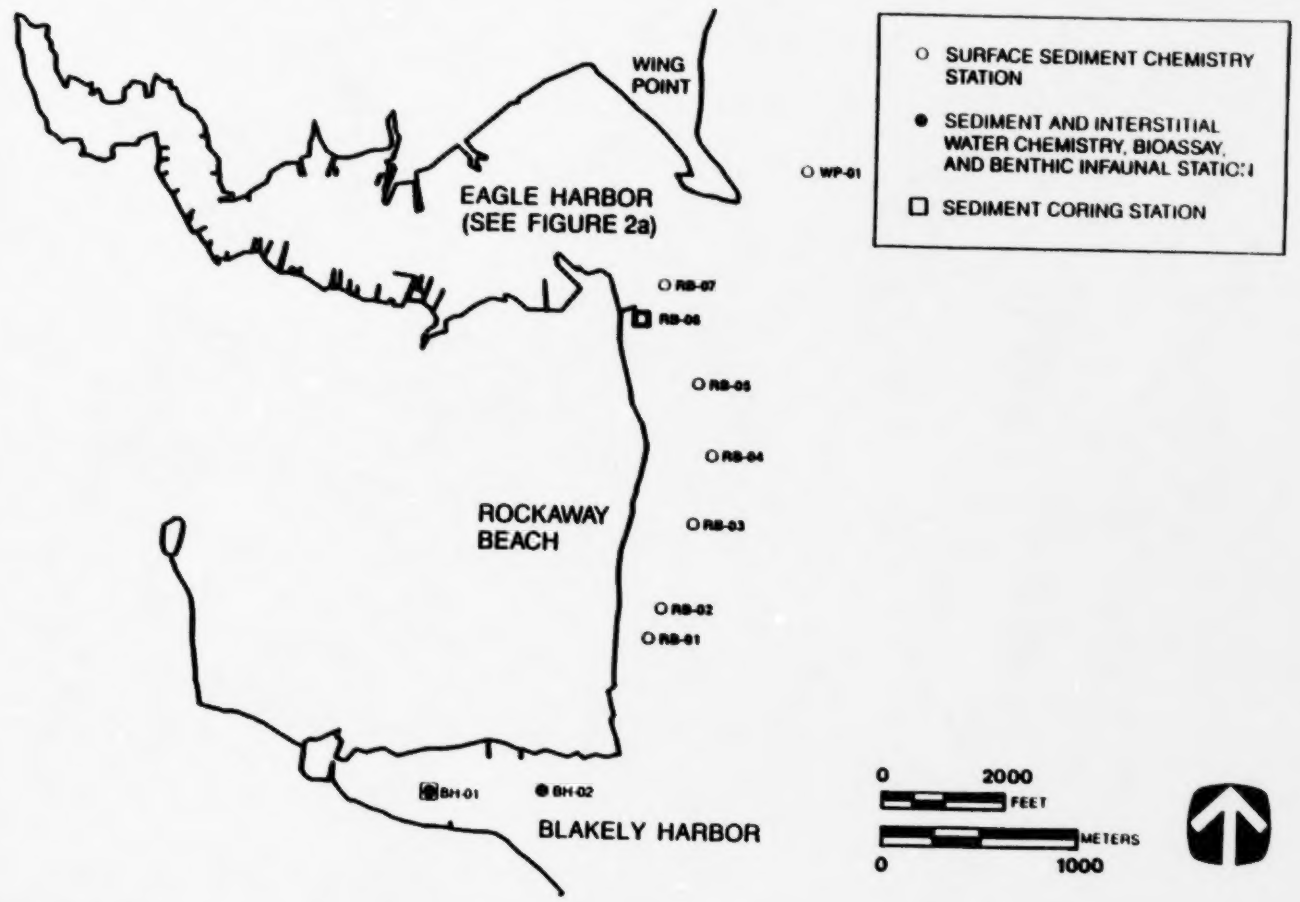

WING POINT
EAGLE HARBOR (SEE FIGURE 2a)
ROCKAWAY BEACH
BLAKELY HARBOR
WP-01
RB-07
RB-06
RB-05
RB-04
RB-03
RB-02
RB-01
BH-01
BH-02
○ SURFACE SEDIMENT CHEMISTRY STATION
● SEDIMENT AND INTERSTITIAL WATER CHEMISTRY, BIOASSAY, AND BENTHIC INFAUNAL STATION
☐ SEDIMENT CORING STATION
0
2000
FEET
METERS
0
1000

Figure B-20. Sample station locations in Blakely Harbor reference area. (Reference: Barrick et al. 1986).

## TABLE B-3. BIOLOGICAL EFFECTS STATIONS USED TO APPROXIMATE HIGHEST CHEMICAL CONCENTRATIONS IN PUGET SOUND REFERENCE AREAS

| Survey | Reference Area | Station | Biological Effects Data<br>Amphipod | <br>Oyster | <br>Benthic | <br>Microtox |
|---|---|---|---|---|---|---|
| ALKI | Point Williams | PW-01 | | | X | |
| | | PW-02 | | | X | |
| | | PW-03 | | | X | |
| | | PW-04 | | | X | |
| CBMSQS | Carr Inlet | CR-11 | X[a] | X | X | X |
| | | CR-12 | X | X | X | X |
| | | CR-13 | X | X | X | X |
| | | CR-14 | X | X | X | X |
| DUWRIV1 | Sequim Bay | SQ-09 | X | | | |
| DUWRIV2 | Sequim Bay | SQ-21 | X | | | |
| EBCHEM | Port Susan | PS-01 | X | X | | |
| | | PS-02 | X | X | | |
| | | PS-03 | X | X | | |
| | | PS-04 | X | X | | |
| EVCHEM | Port Susan | PS-02 | X | X | | |
| | | PS-03 | X | X | | |
| | | PS-04 | X | X | | |
| EIGHTBAY | Case Inlet | CS-01 | X | | | |
| | | CS-11 | X | | | |
| | | CS-15 | excluded[b] | | | |
| | | CS-17 | excluded | | | |
| | Dabob Bay | DB-01 | X | | | |
| | | DB-05 | X | | | |
| | | DB-07 | X | | | |
| | | DB-15 | excluded | | | |
| | Samish Bay | SM-01 | X | | | |
| | | SM-03 | excluded | | | |
| | | SM-07 | X | | | |
| | | SM-20 | excluded | | | |
| | Sequim Bay | SQ-14 | X | | | |
| | | SQ-17 | X | | | |
| | | SQ-18 | X | | | |
| | | SQ-20 | X | | | |

[a] X = Biological test results used for calculation of highest reference area concentration.

[b] Sample exhibited amphipod mortality that exceeded recommended guidelines for reference area characterization (e.g., mortality was >25 percent); these samples were excluded from determination of highest reference area concentrations.